Eastern Renewable Generation Integration Study

Technical Review Committee

November, 2013

Aaron Bloom

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NREL is a national laboratory of the U.S. Department of Energy, Office of Energy Efficiency and Renewable Energy, operated by the Alliance for Sustainable Energy, LLC.

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Agenda

Morning

- Datasets
    - Solar Data
    - Wind Data
    - VG Analysis
    - Solar Forecasts
    - Load
    - Hydro Limits
    - Thermal Expansion

Afternoon

- Benchmarking
    - 2010 Database
    - Generation
    - Interchange
- Transmission Representation
- Run-time Reduction Efforts
- 3-Month Plan
    - 2025 Simulations
    - HPC
    - Other

Recap: ERGIS

- **Motivation**
  - How do high penetrations of solar and wind generation impact system operations of the Eastern Interconnection?
- **Approach**
  - Assemble a Technical Review Committee to guide the development of a database that accurately characterizes the Eastern Interconnection. Then use an advanced mixed integer model to analyze renewable generation at a sub-hourly resolution.

Study Limitations

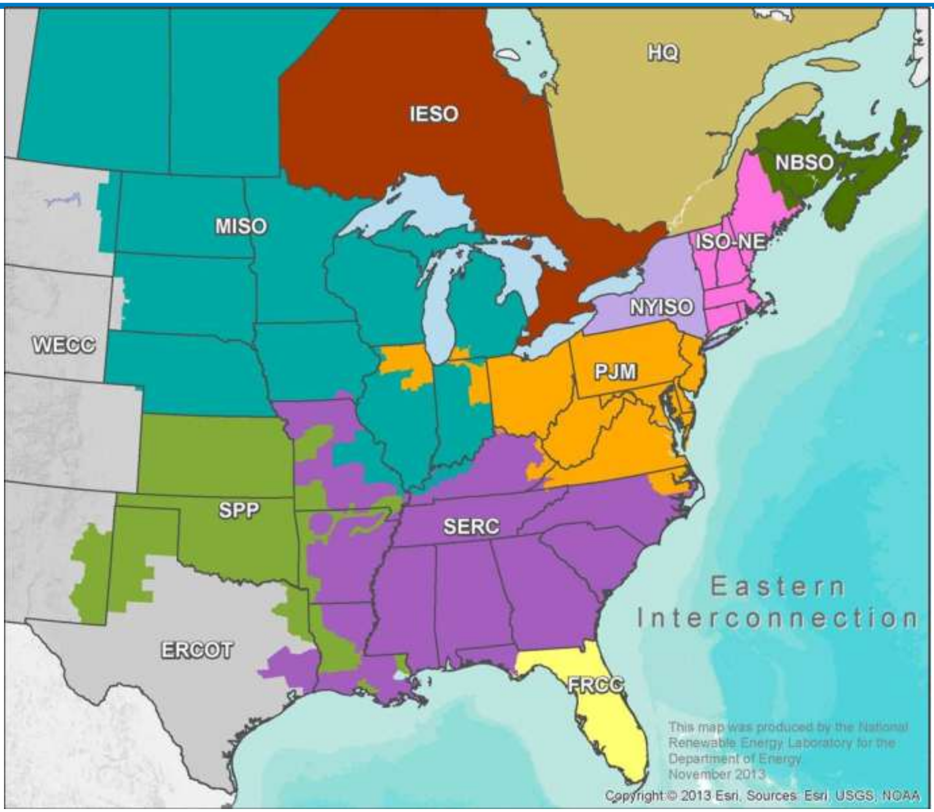
- **We lack:**
  - Bilateral power purchase and other contractual agreement data
  - Detailed operational constraints and/or complete unit-specific data in the generation models
  - Capability to simultaneously model different dispatch intervals in different balancing authority areas
- **Uncertainties:**
  - Future cooperation and/or sub-hourly dispatch across the interconnection
  - The amount and location of variable generation
  - Transmission system additions
  - Generation additions and retirements
  - Gas and coal prices

Operational Areas of Interest

- **Reserves**
  - Types
  - Quantities
  - Sharing
- **Commitment and Dispatch**
  - Day-ahead
  - 4-hour-ahead
  - Real-time
- **Interchange Scheduling**
  - 1-hour
  - 15-minute
  - 5-minute

Scenario Overview

- Designed to:
  - Bookend two approaches to renewables
    - National implementation
    - Regional implementation
  - Highlight impact of additions of renewables
- Generation expansion using ReEDS



	Energy Penetration (%)		Solar PV Capacity (GW)		Wind Capacity (GW)		Conventional Capacity (GW)			
Scenario	Solar	Wind	Rooftop	Utility	Onshore	Offshore	Nuclear	Coal	CC	CT & Boiler
Low Renewables	0	3	1	0	30	0	88	231	147	194
State RPS	0.2	12	3	2	91	15	88	230	144	197
Regional 30%	10	20	96	123	168	46	88	212	133	173
National 30%	5	25	50	123	237	27	88	216	137	178

Wind and Solar Datasets

Developing and Refining

- **Large integration studies are data intensive**
- **Datasets**
  - Heat rates
  - Canadian system
  - Solar and Wind profiles
  - Load
  - Hydro
  - Thermal fleet
  - Transmission

Solar Data

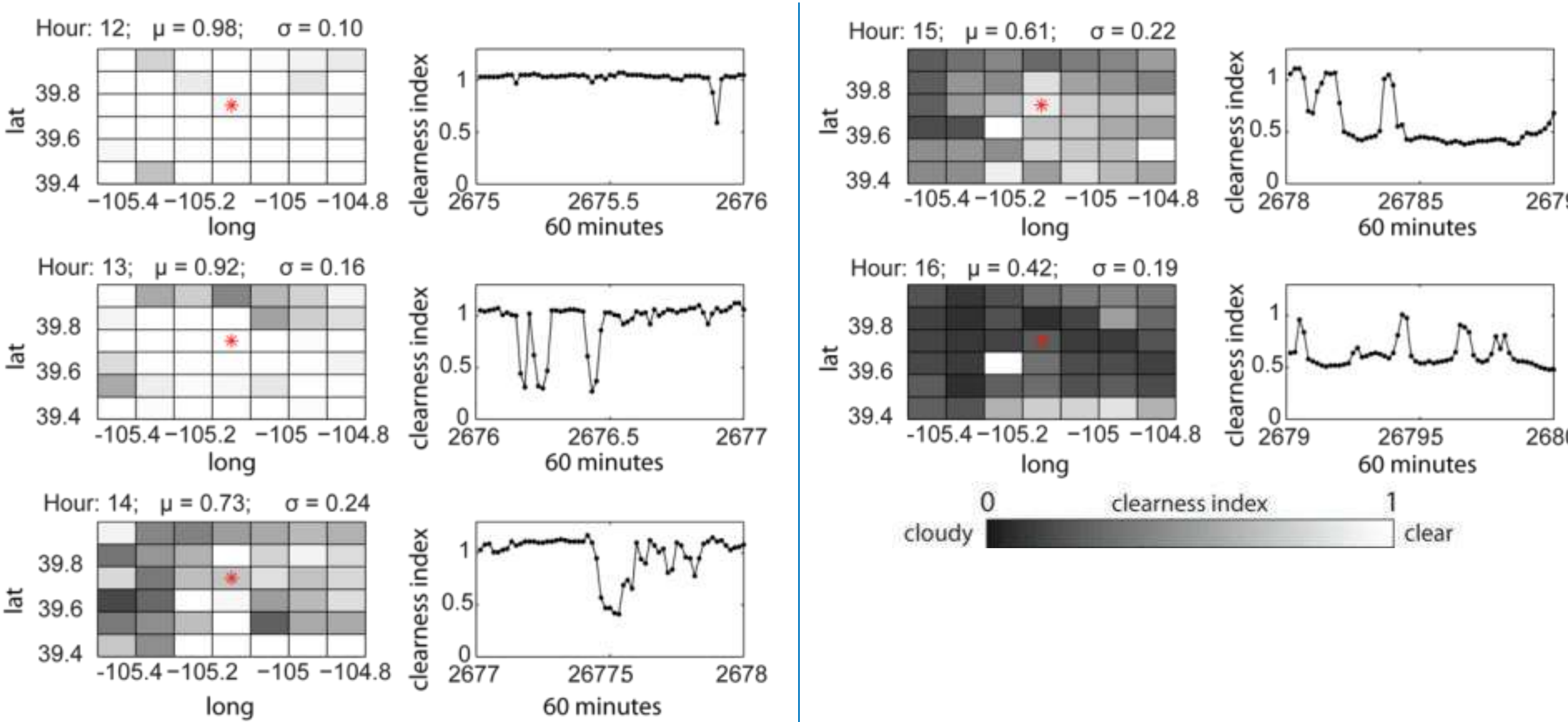
- New dataset for the Eastern Interconnection
- 5-minute resolution
- Rooftop Solar: 40% of all solar generation
- Utility PV: 60% of all solar generation
- State RPS Scenario reflect solar-specific RPS carve outs

Developing Solar Profiles

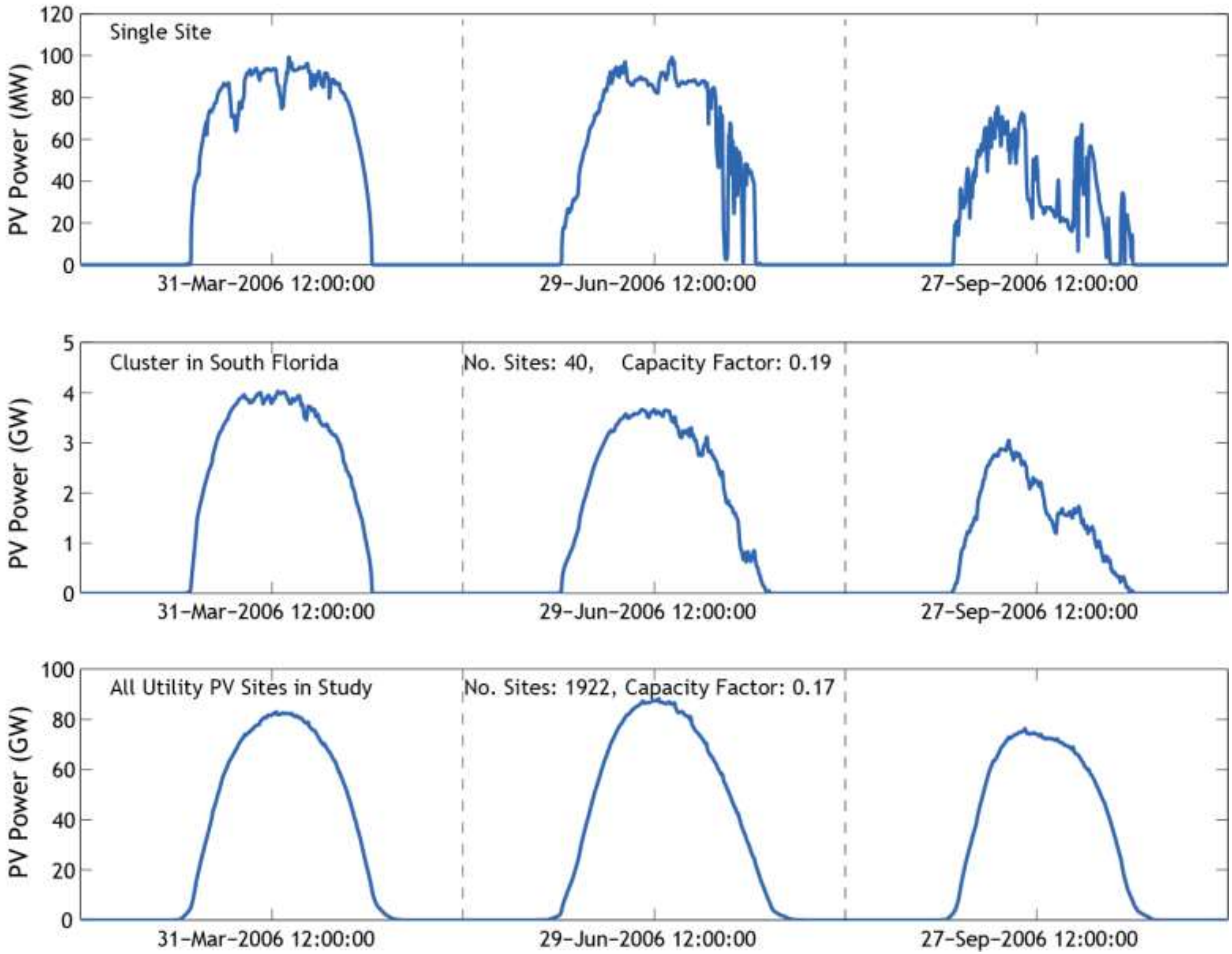
- Replicate the injection of power into the transmission system from individual solar plants
- Produces statistically probable values of irradiance
- Temporal resolution of one minute
- Derived from hourly satellite data (see March 2013 TRC)

Site Clearness Index Analysis

Spatial satellite data is used to calculate the relative proportions of cloud cover in an area for each hour. This data is related to the sub-hourly measurements of irradiance. These figures show five consecutive hours of aerial satellite data (left) and corresponding ground-based time-series irradiance data (right).



Time Series and Aggregation



Caveats

- **Not verified against actual solar data**
- **Satellite data is not perfect**
  - Some missing satellite images
  - Statistical solutions necessary for 8 hours of missing data

Eastern Wind Dataset

About the data

- Sites: 1,326
- Years: 2004-2006
- Time: 10-minute resolution
- Capacity: 580 GW
- Mesoscale model
- 2 km resolution
- Multiple forecasts

Where to get it:

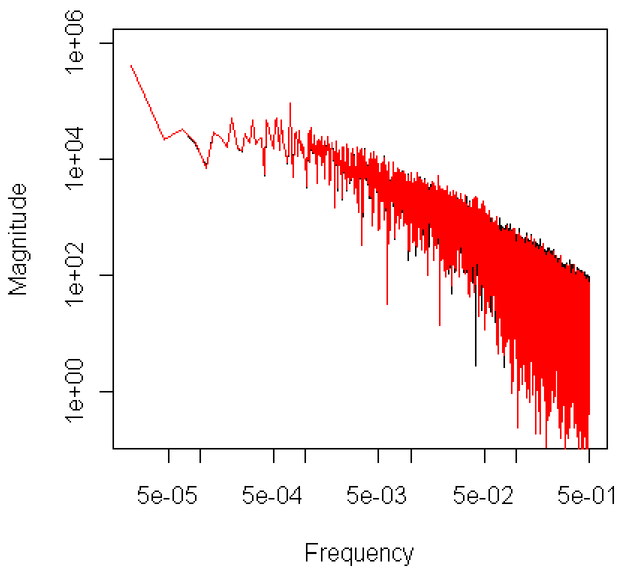
http://www.nrel.gov/electricity/transmission/eastern_wind_methodology.html

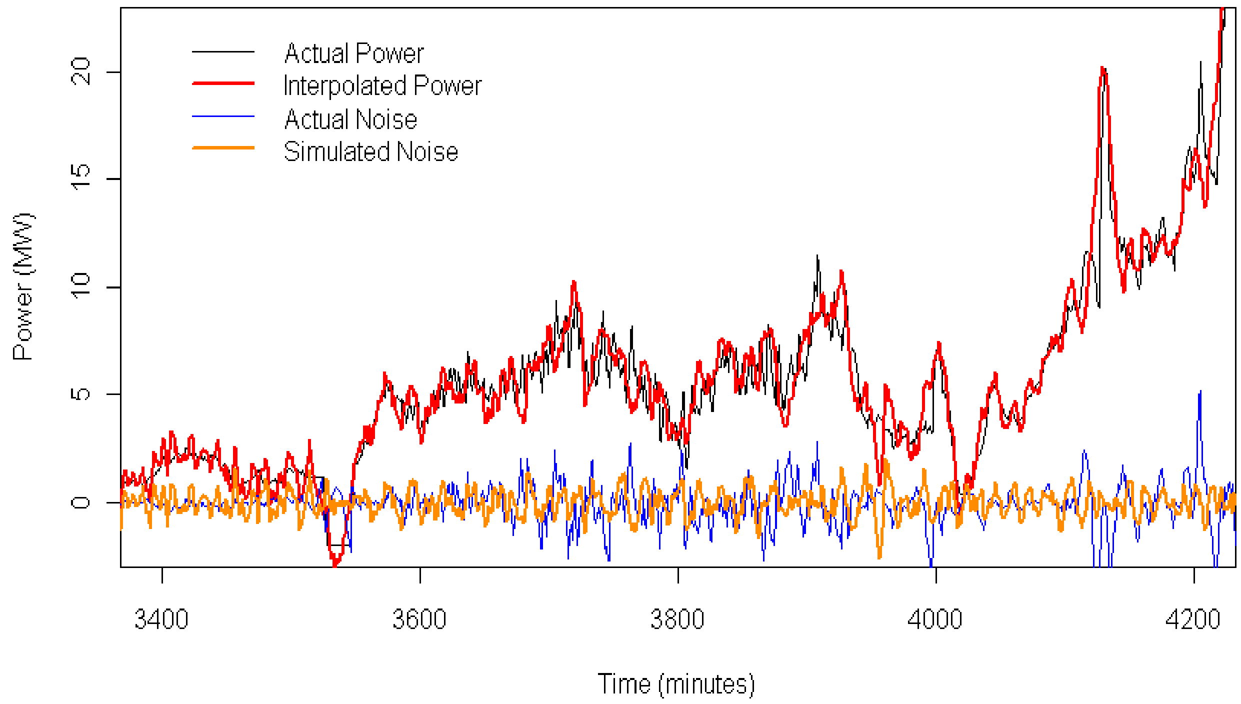
Sub-Hourly Wind Data

- **Eastern Wind Dataset is 10-minute resolution**
- **ERGIS is running 5-minute real time simulations**
- **Fast Fourier Transform (FFT)-based method for synthesizing 5-minute data from 10-minute data**
  - Not simple interpolation

Examples of Wind Power Variability Simulation*

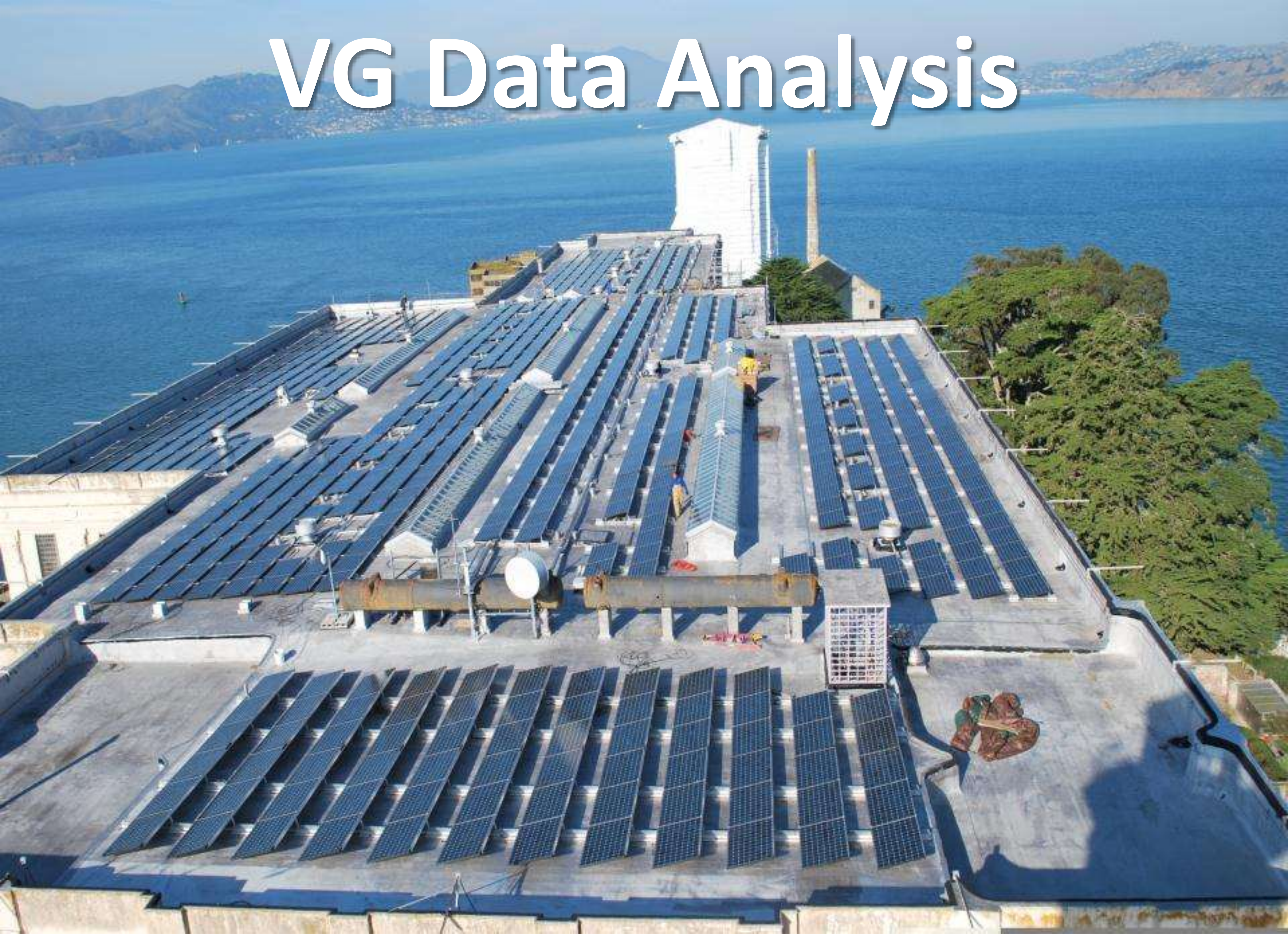
*turning 10-minute wind power data into 5-minute data





August

VG Data Analysis



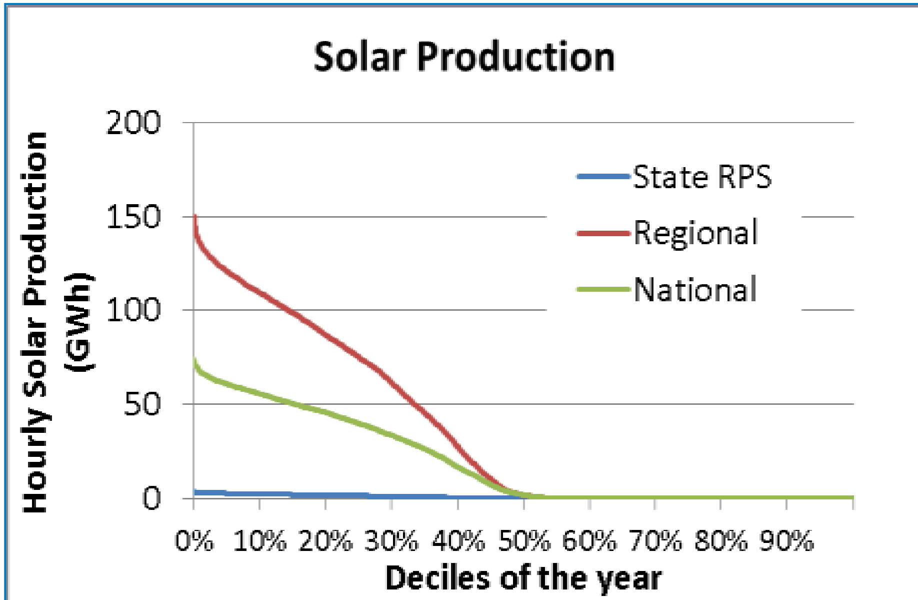
Wind and Solar Data Analysis

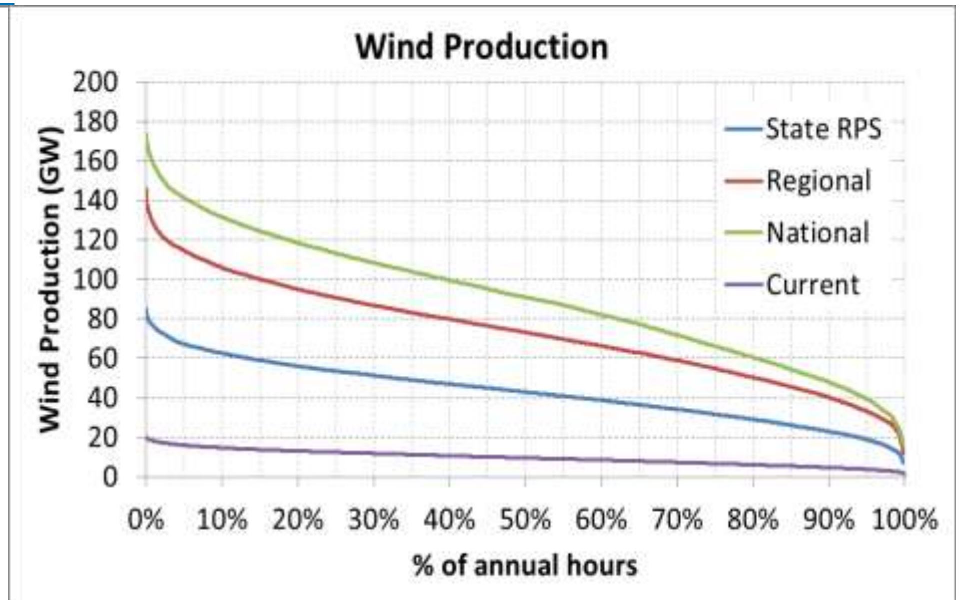
- **Understand the variability and uncertainty of wind and solar resources across a variety of time periods**
  - Annual
  - Monthly
  - Hourly
  - Sub-hourly (forthcoming)

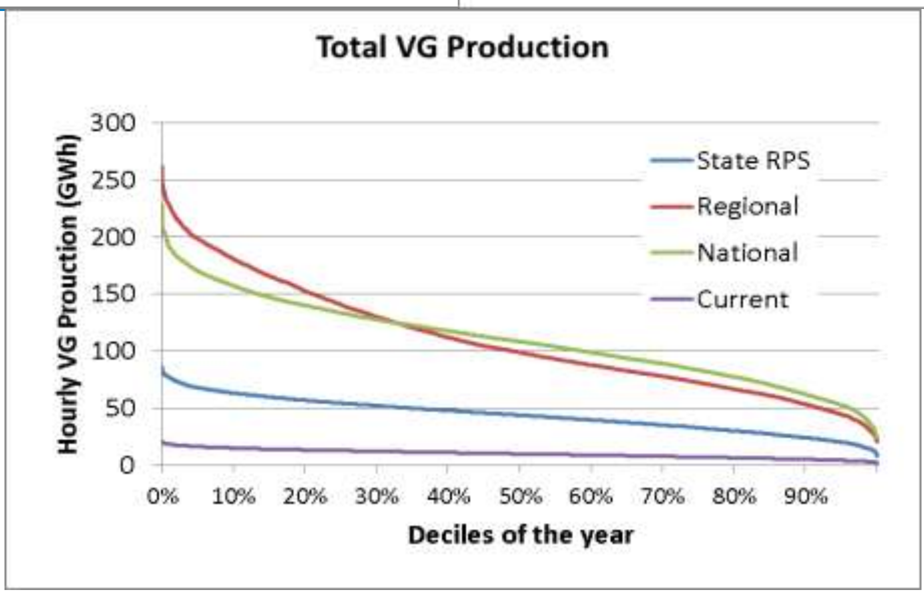
Annual Analysis

- **The two 30% scenarios have significantly different peak values**
  - 10% solar penetration in regional scenario
  - 5% solar penetration in national scenario
- **The two 30% scenarios have roughly 2.5 times the VG penetration of the State RPS Scenario**
- **State RPS scenario and National scenario are shaped similarly because they both have predominately wind.**

Annual Production of Variable Generation



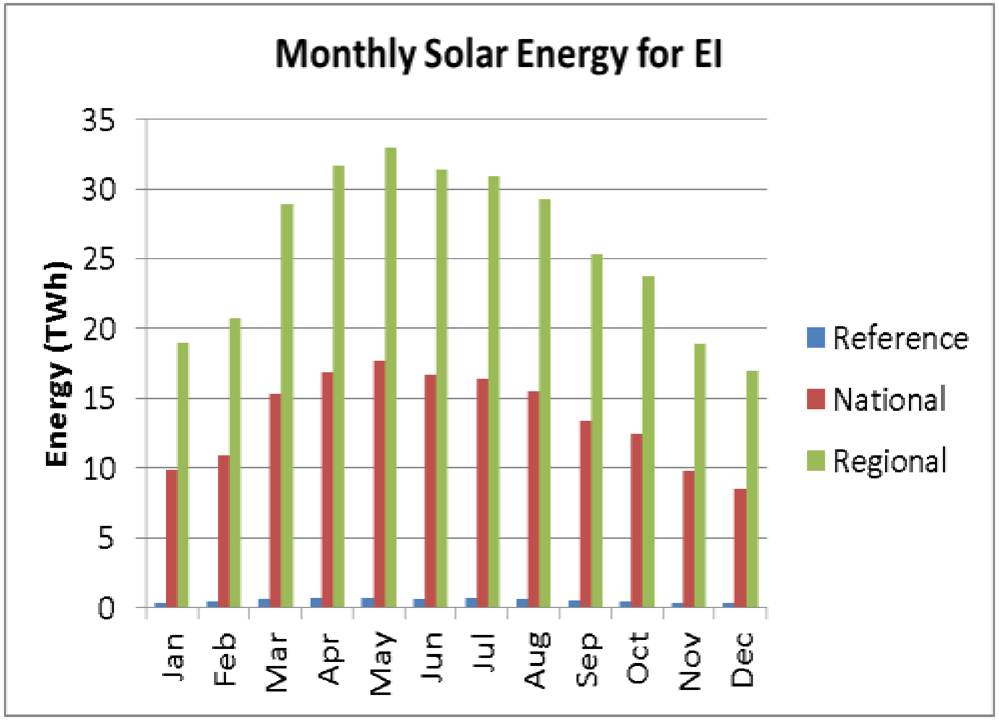




Monthly Solar Energy

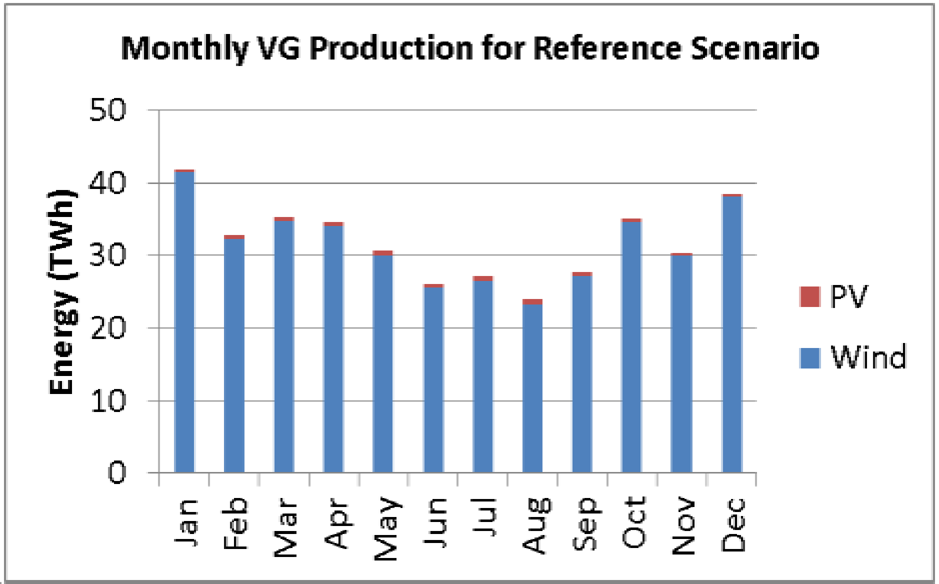
- **The Regional 30% Scenario has roughly twice as much PV as the National 30% Scenario**
- **May peak and December minimum**

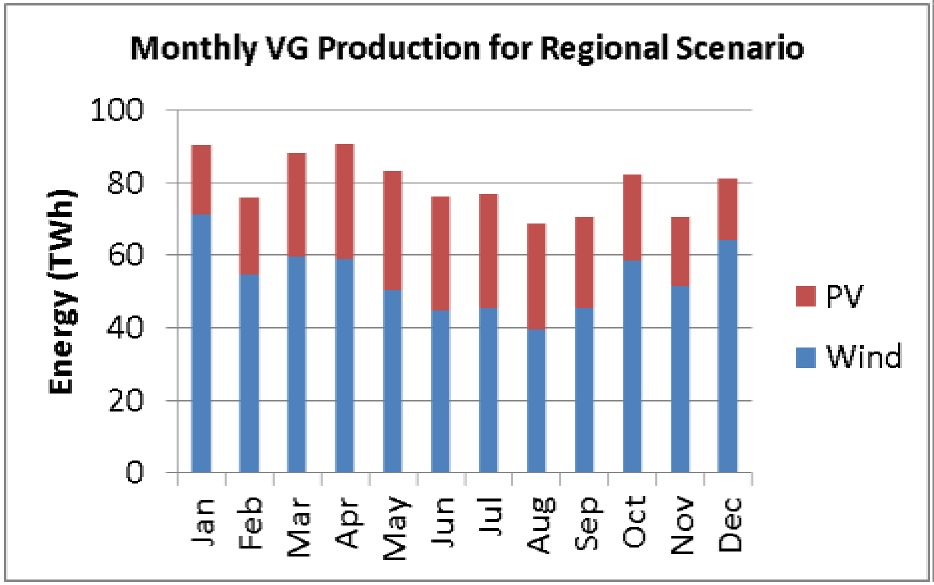
Scenario	Annual Solar Production (TWh)
State RPS	6
Regional 30%	310
National 30%	165

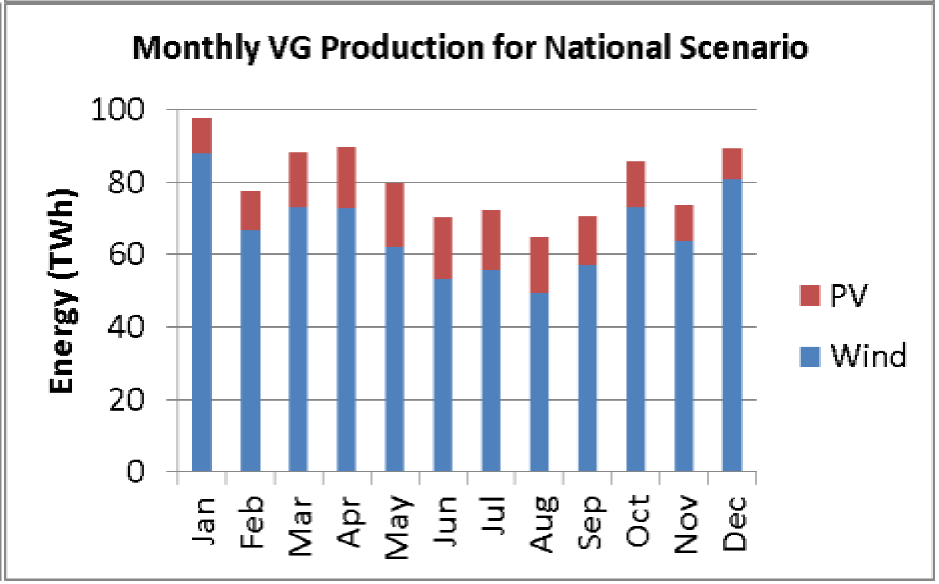


VG Monthly Analysis

- Production follows anticipated monthly patterns
- Highest solar production April through July
- Highest wind production in winter and spring

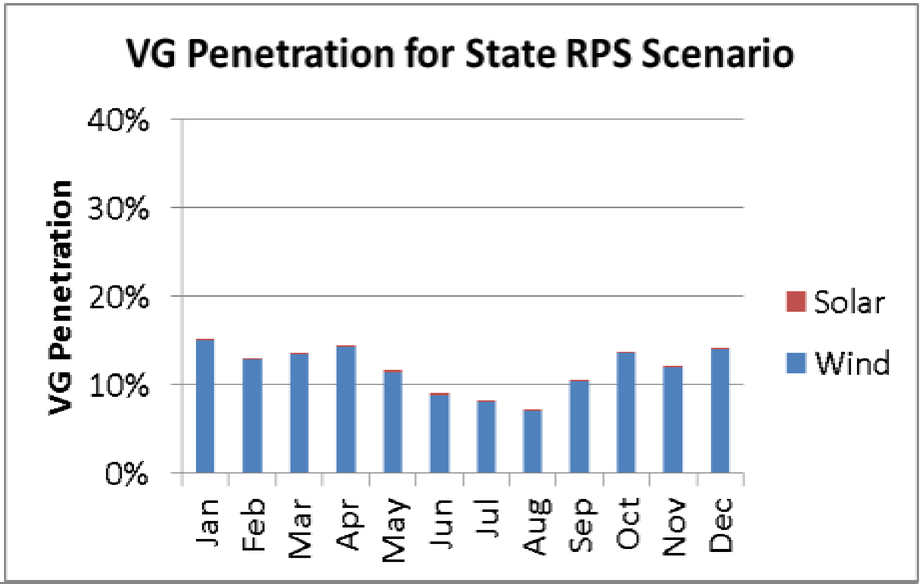


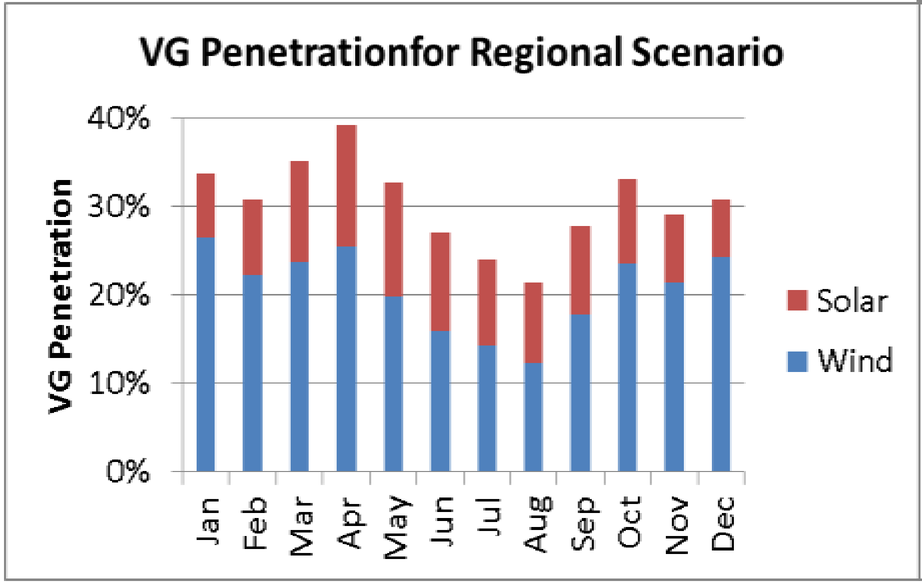


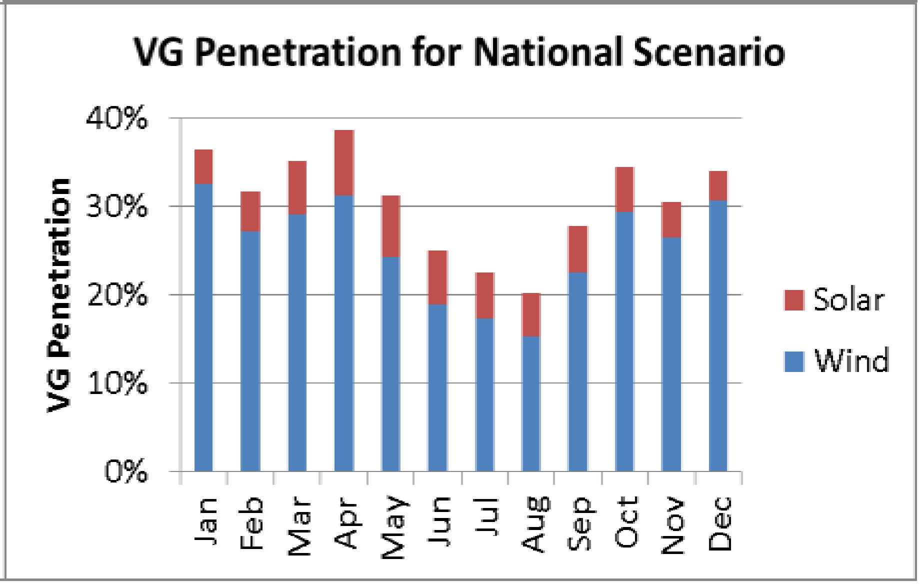


VG Monthly Penetration

- Penetration as low as 20% in August
- Nearly 40% in April

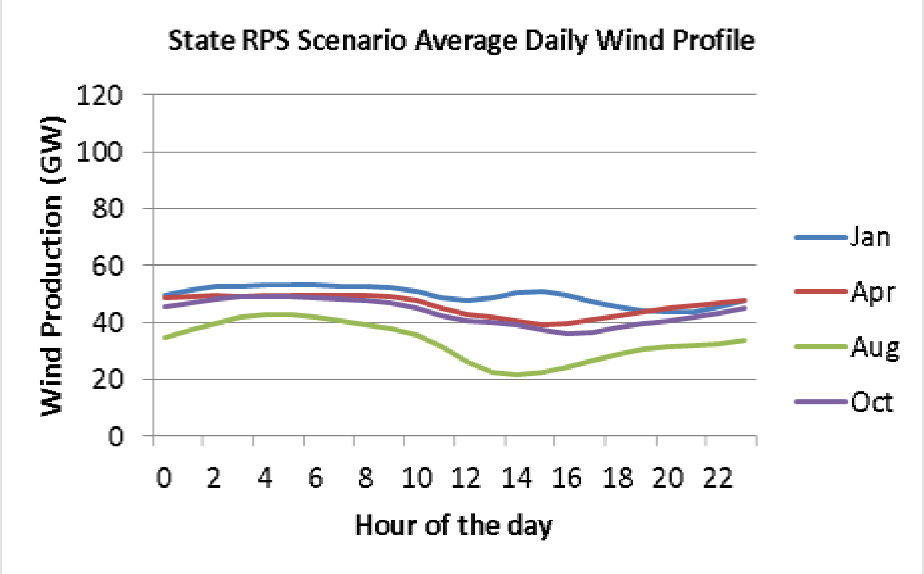


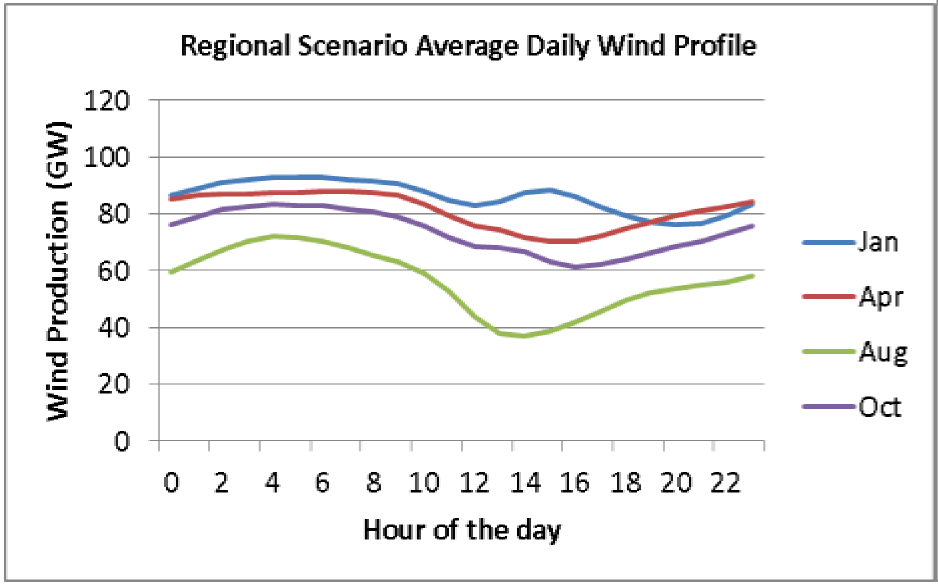


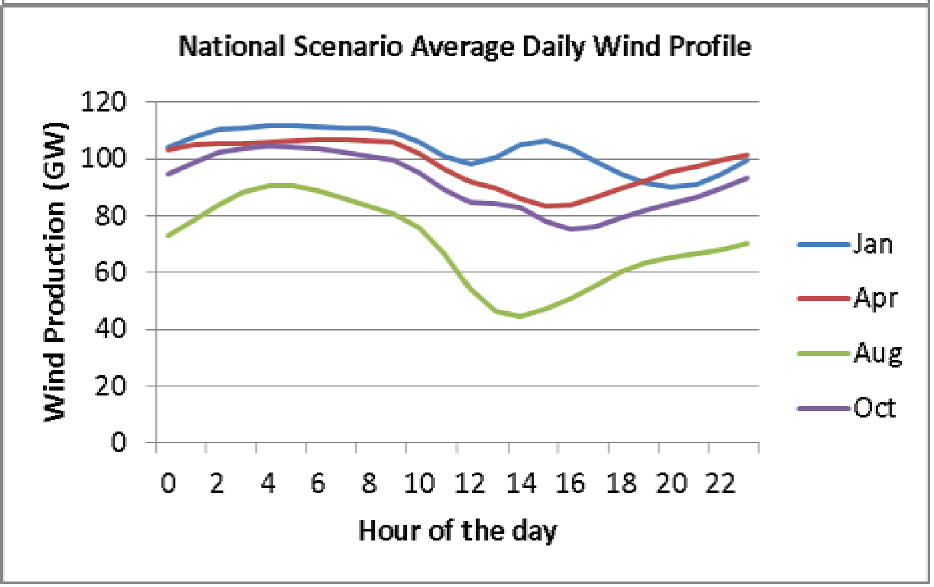


Average Diurnal Wind Variation

- Most of the year has nighttime peaks and afternoon minimums
- Late fall and winter there is a peak in the late afternoon/early evening
- Most production in winter, least in the summer
- Mostly anti-correlated with load
- Note different scales

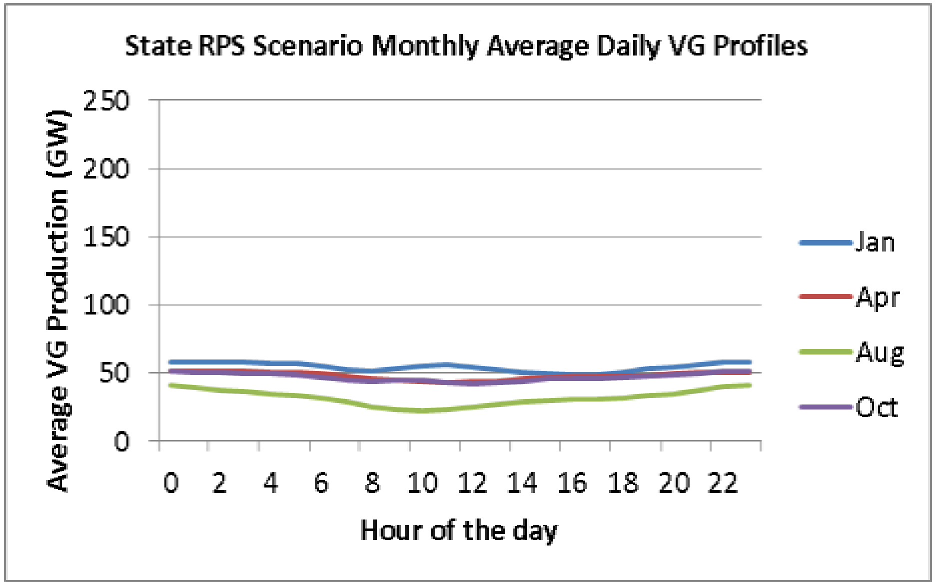


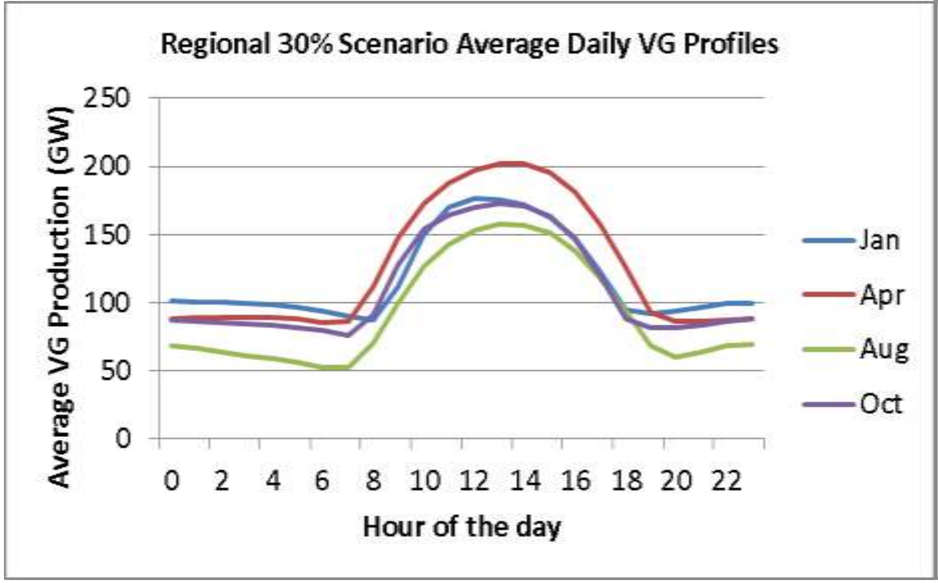


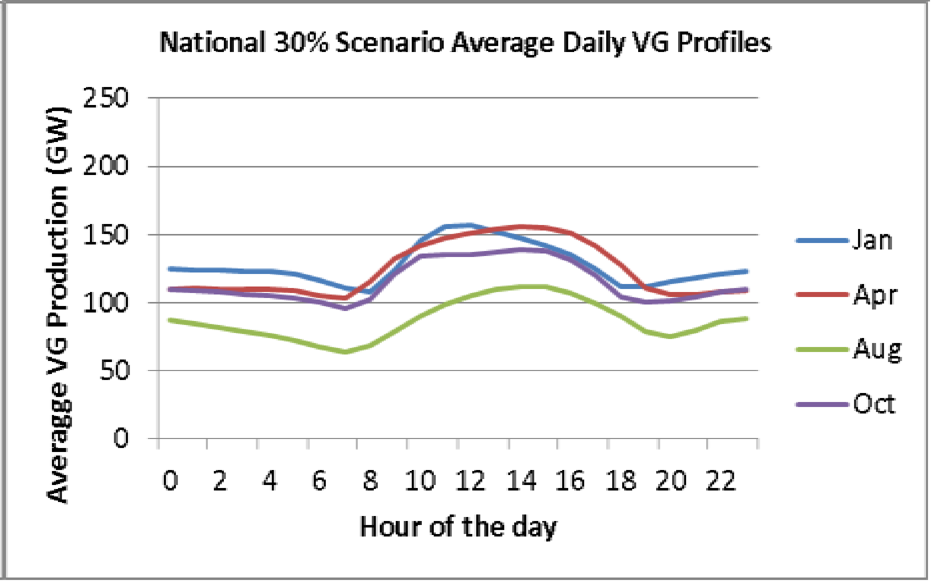


Average Diurnal VG Variation

- The State RPS Scenario has very little solar influence in the daytime results
- High penetrations of solar in the Regional 30% Scenario is clearly apparent
- The National 30% Scenario has a smaller impact on peak production
- The high solar scenarios follow a typical load curve for summer months, but are slightly shifted earlier in the day

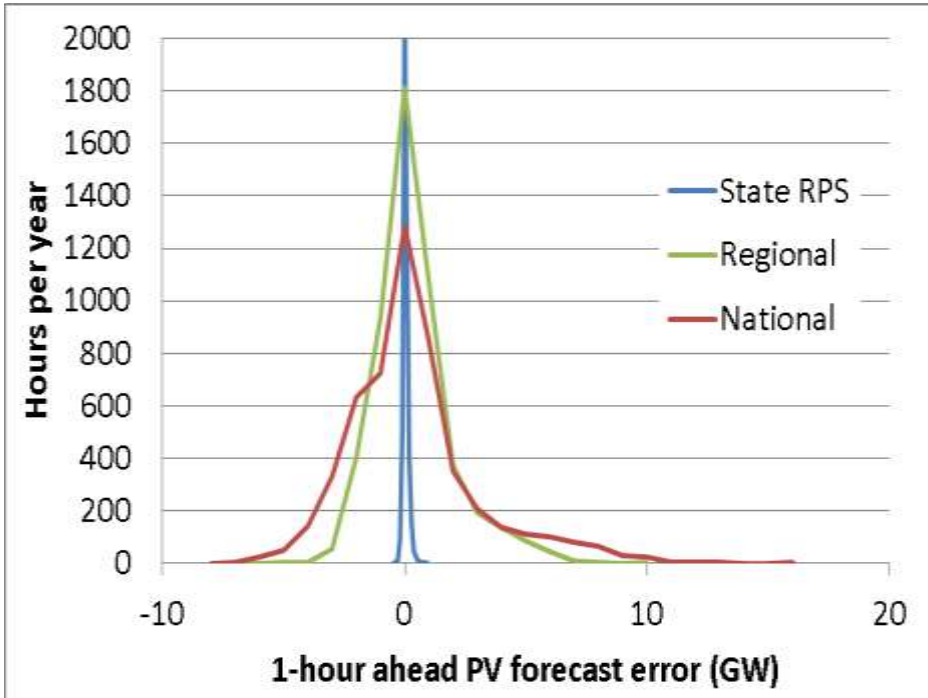


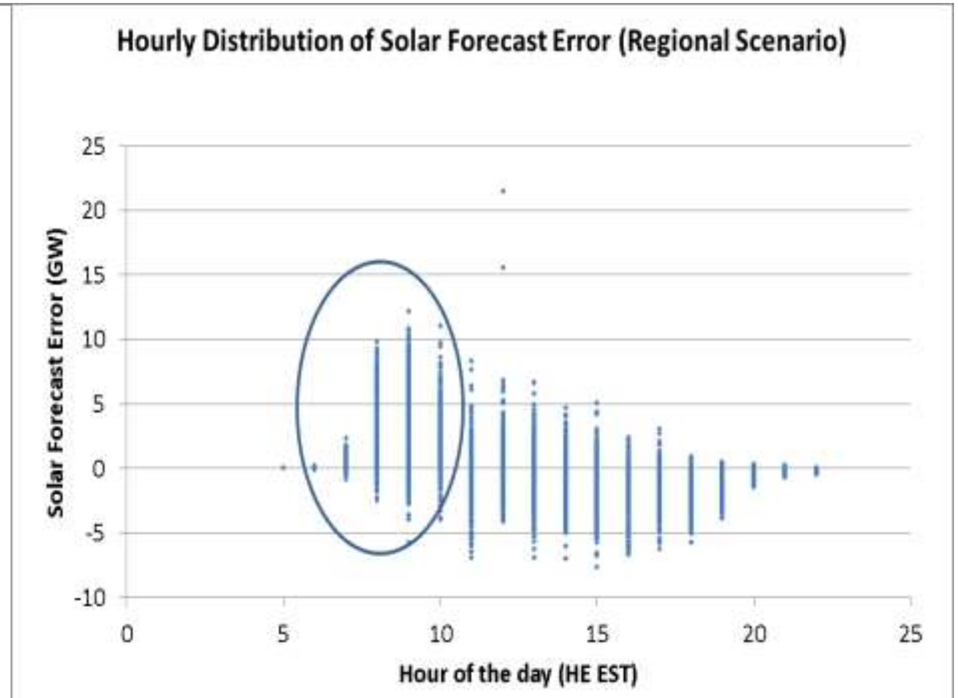




Solar Hour-Ahead Uncertainty

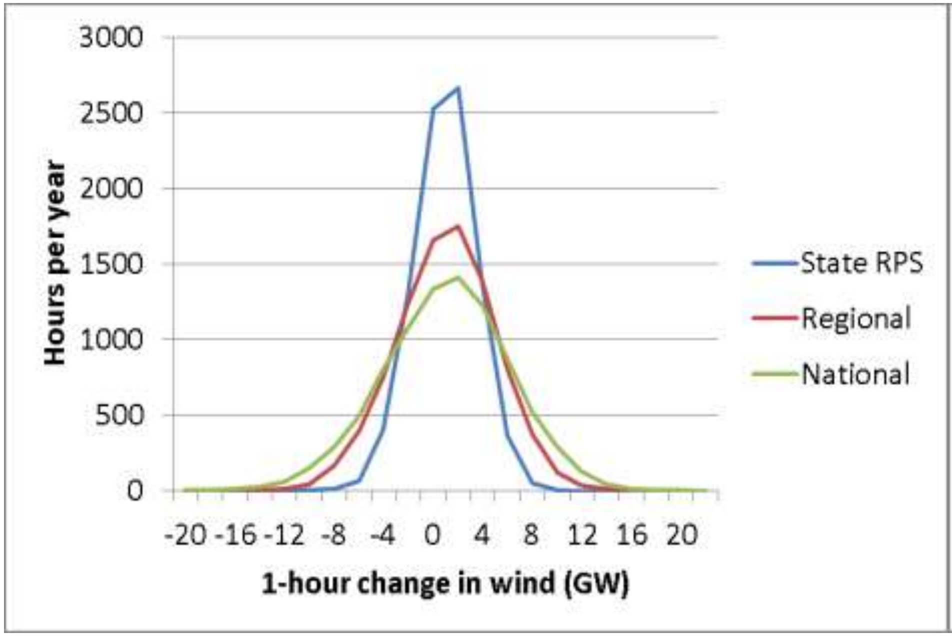
- Solar uncertainty is calculated considering arc of the sun producing an hour ahead forecast error
- The National 30% Scenario has less uncertainty than the Regional 30% Scenario
- Asymmetry in distribution of hour-ahead uncertainty is due to high uncertainty in the morning hours

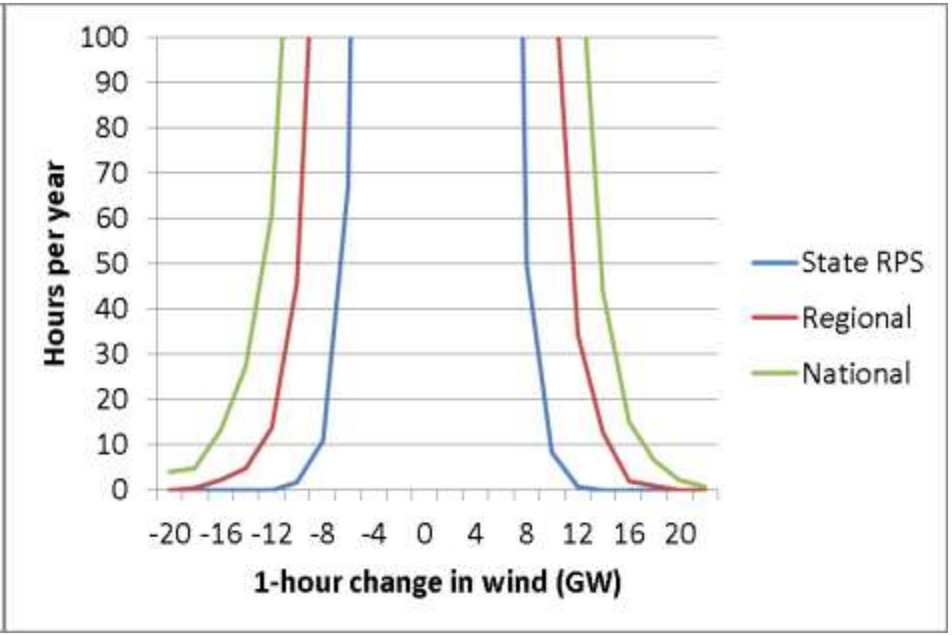




Wind Hourly Uncertainty

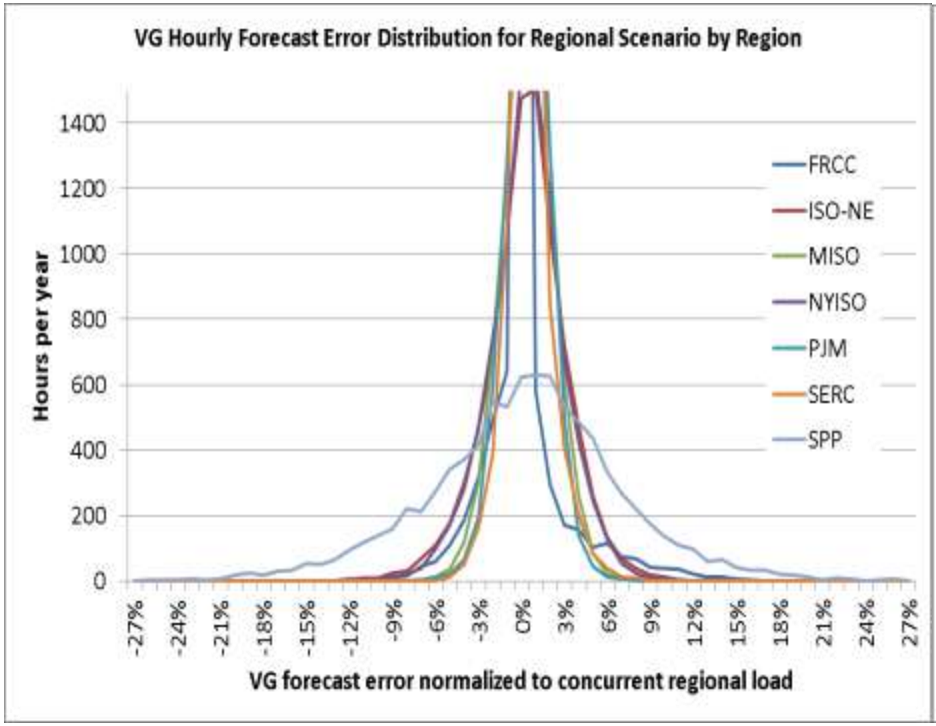
- As the nameplate increases for a region for each scenario the maximum ramp size decreases relative to the wind nameplate capacity
- The variability as measured by the standard deviation (sigma) of the hour-to-hour changes also shows a relative decrease with increasing wind capacity

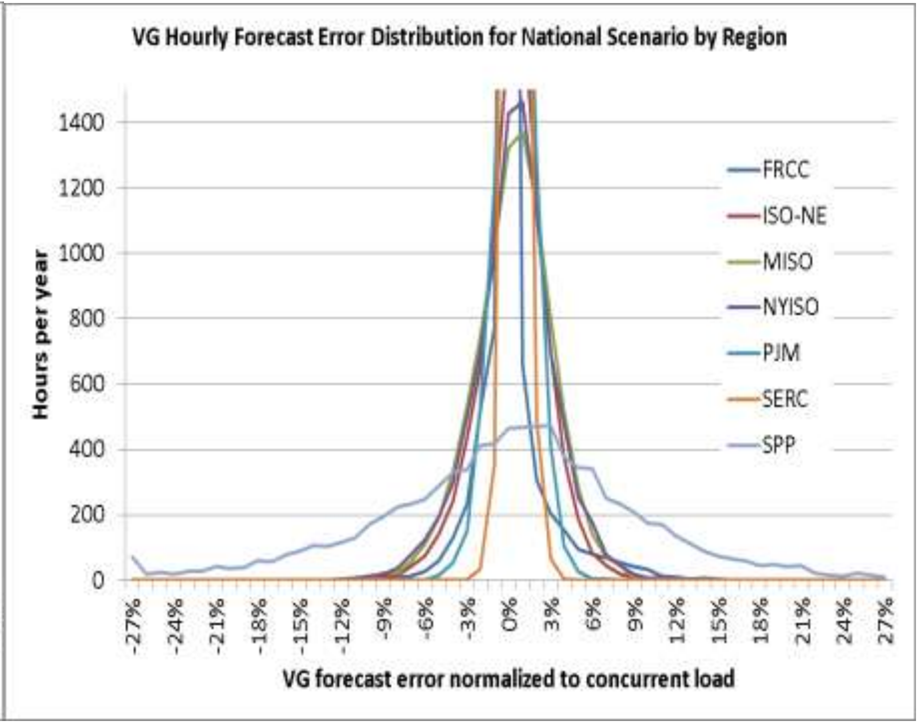




Regional VG Hour-Ahead Uncertainty

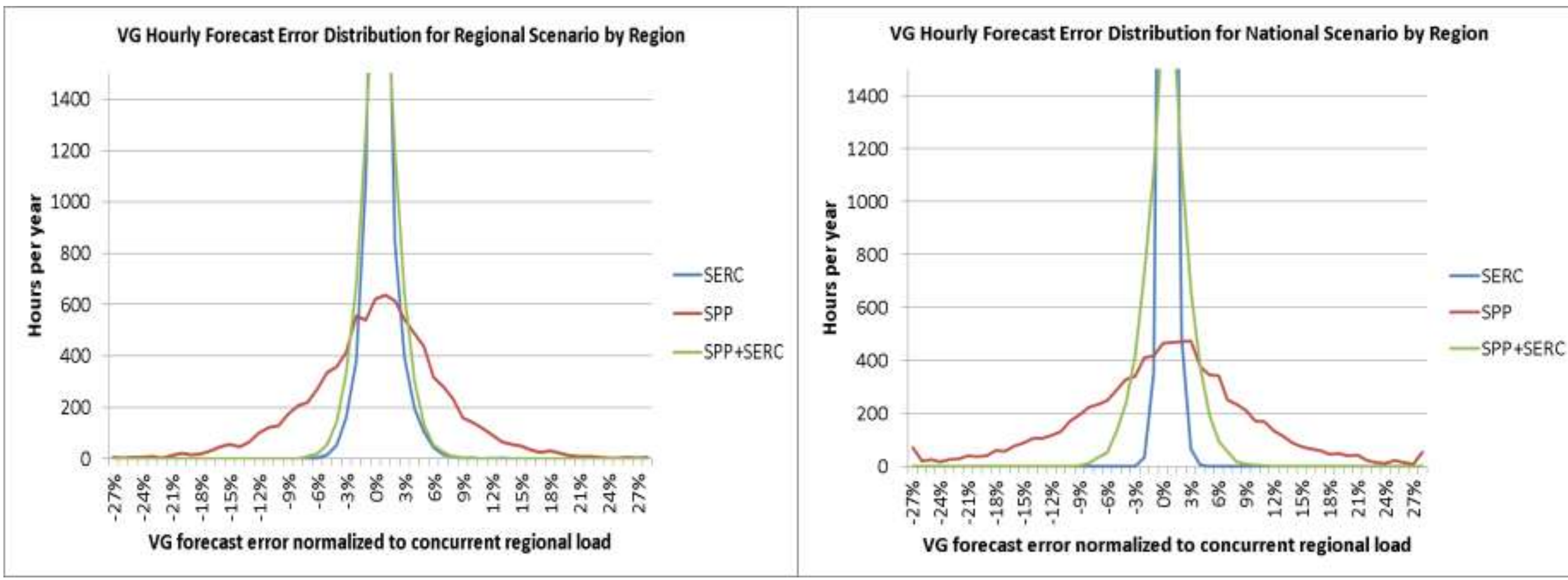
- Hourly unforecasted ramps normalized to concurrent regional load
- SPP sees the widest distribution and has the highest penetration in both scenarios
- In Regional Scenario most distributions similar with similar penetrations - FRCC is all solar so slightly narrower





Detail of SERC and SPP HA Uncertainty

- 44% (Regional Scenario) and 67% (National Scenario) of SPP VG production is exported
- In National Scenario, SPP penetration is 91%
- Combined data gives similar results to other regions



Total VG Hour-Ahead Uncertainty

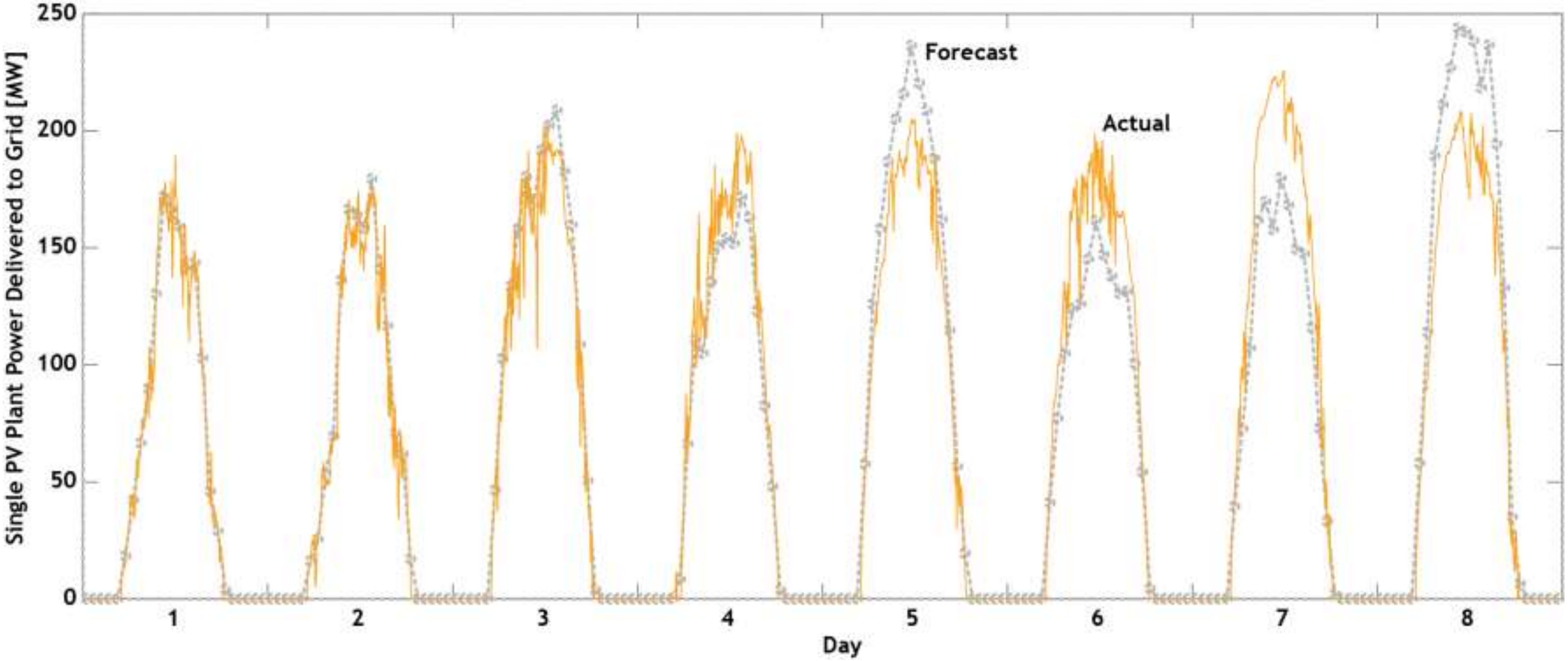
		FRCC	ISO-NE	MISO	NYISO	PJM	SERC	SPP	E. I.
State RPS Scenario									
Capacity	MW		7225	42411	11817	27358	2368	27835	119015
Sigma	MW		290	1255	460	631	273	1168	2434
	%		4%	3%	4%	2%	12%	4%	2%
Largest Negative	MW		-1299	-6086	-1950	-3164	-2072	-4501	-10099
Forecast Error	%		-18%	-14%	-17%	-12%	-87%	-16%	-8%
Largest Positive	MW		1704	7200	1900	3219	1881	6281	11488
Forecast Error	%		24%	17%	16%	12%	79%	23%	10%
Regional Scenario									
Capacity	MW	45733	14970	75544	17062	85424	54739	59683	353155
Sigma	MW	822	423	1607	478	1580	1244	1808	3990
	%	2%	3%	2%	3%	2%	2%	3%	1%
Largest Negative	MW	-5202	-1757	-7217	-2031	-7898	-5113	-7656	-18577
Forecast Error	%	-11%	-12%	-10%	-12%	-9%	-9%	-13%	-5%
Largest Positive	MW	6276	2456	9483	2396	7018	8673	9823	22270
Forecast Error	%	14%	16%	13%	14%	8%	16%	16%	6%
National Scenario									
Capacity	MW	36324	11671	103991	16525	61876	34421	78169	342976
Sigma	MW	640	357	2511	526	1417	517	2533	4909
	%	2%	3%	2%	3%	2%	2%	3%	1%
Largest Negative	MW	-3844	-1593	-11561	-2346	-6945	-2559	-11371	-21781
Forecast Error	%	-11%	-14%	-11%	-14%	-11%	-7%	-15%	-6%
Largest Positive	MW	4795	2036	12769	2215	6934	3493	13123	22532
Forecast Error	%	13%	17%	12%	13%	11%	10%	17%	7%


Solar Forecasts

Solar Forecasts

- **Objective: Produce a solar forecast for day-ahead and four-hour-ahead grid modeling.**
- **Plan:**
  - Develop three solar forecasts:
    - Persistence
    - Global Forecasting System (NOAA: http://www.nco.ncep.noaa.gov/pmb/products/gfs/)
    - Weather Research and Forecasting (WRF) Model
  - Calculate the forecast error by site/region, season, and capacity
  - Pick the forecast dataset with the least error

Forecasts for Integration Studies



1. Forecasts are classified by the number of hours from the time the forecast was made.
2. Forecast error increases with the length of the forecast.

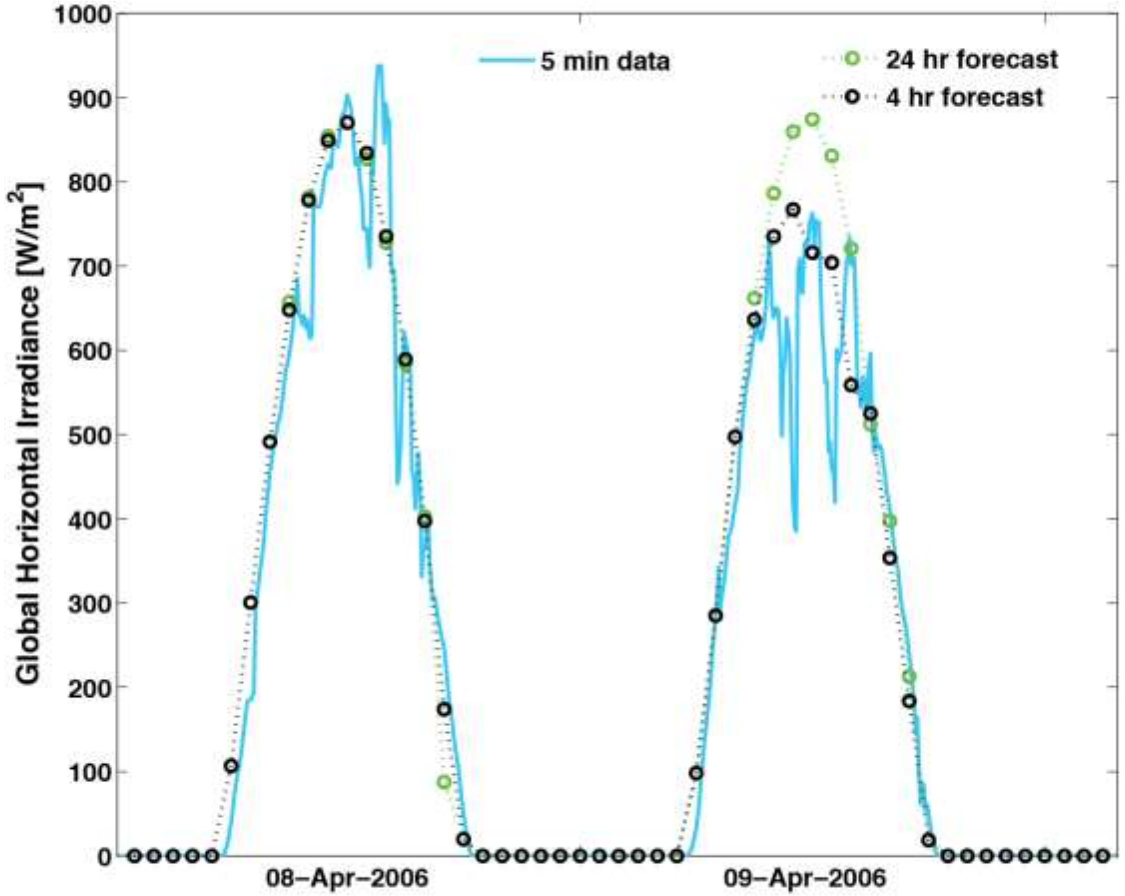
ERGIS – Day Ahead and 4-Hour Ahead

Day-ahead model uses:
“24-hour Forecast”

4-hour ahead model uses:
“4-hour Forecast”

5-minute dispatch uses:
“5-min actual data”

The error between the forecasted wind and solar power output and the real time output is mitigated by changing the dispatch point of committed generators, using storage or demand response and by committing additional “fast start” units.

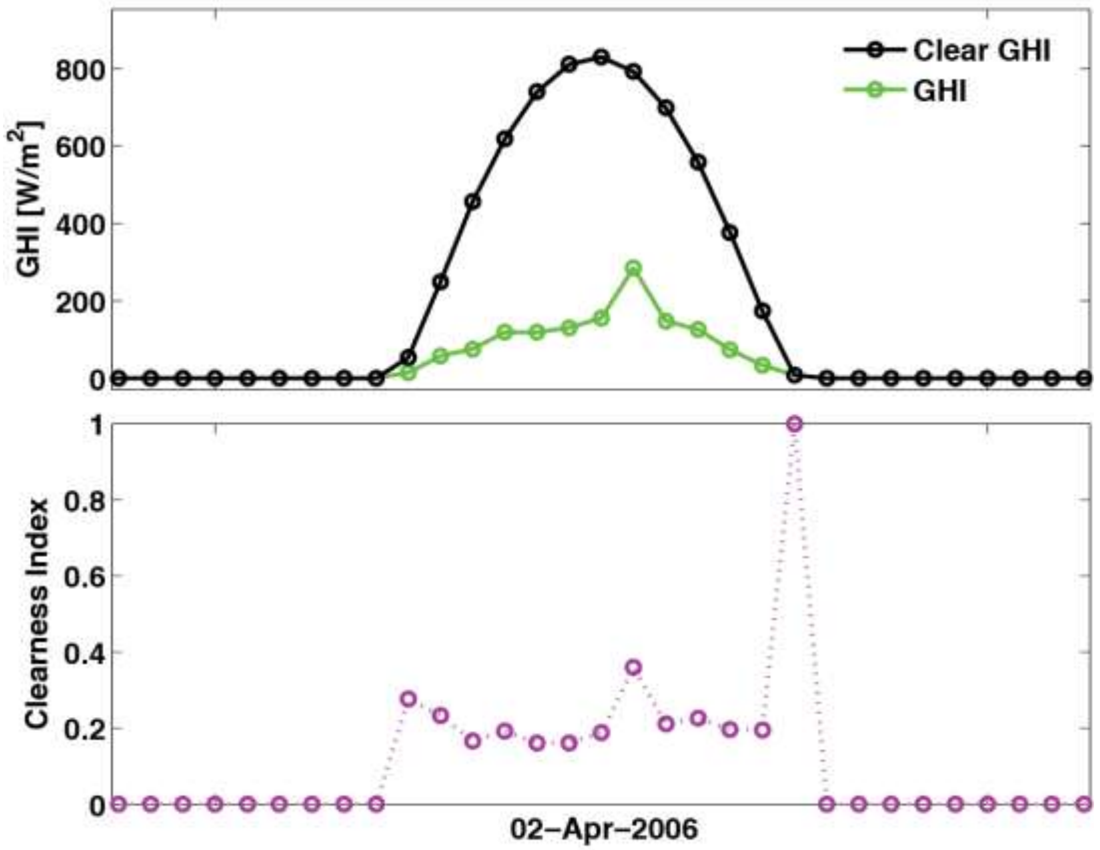


Forecasting Methods: Persistence

Persistence is the “worst case” forecast

24-hour ahead: persistence of the clear power index from the previous day

4-hour ahead: persistence of clear power index from 2-hours before



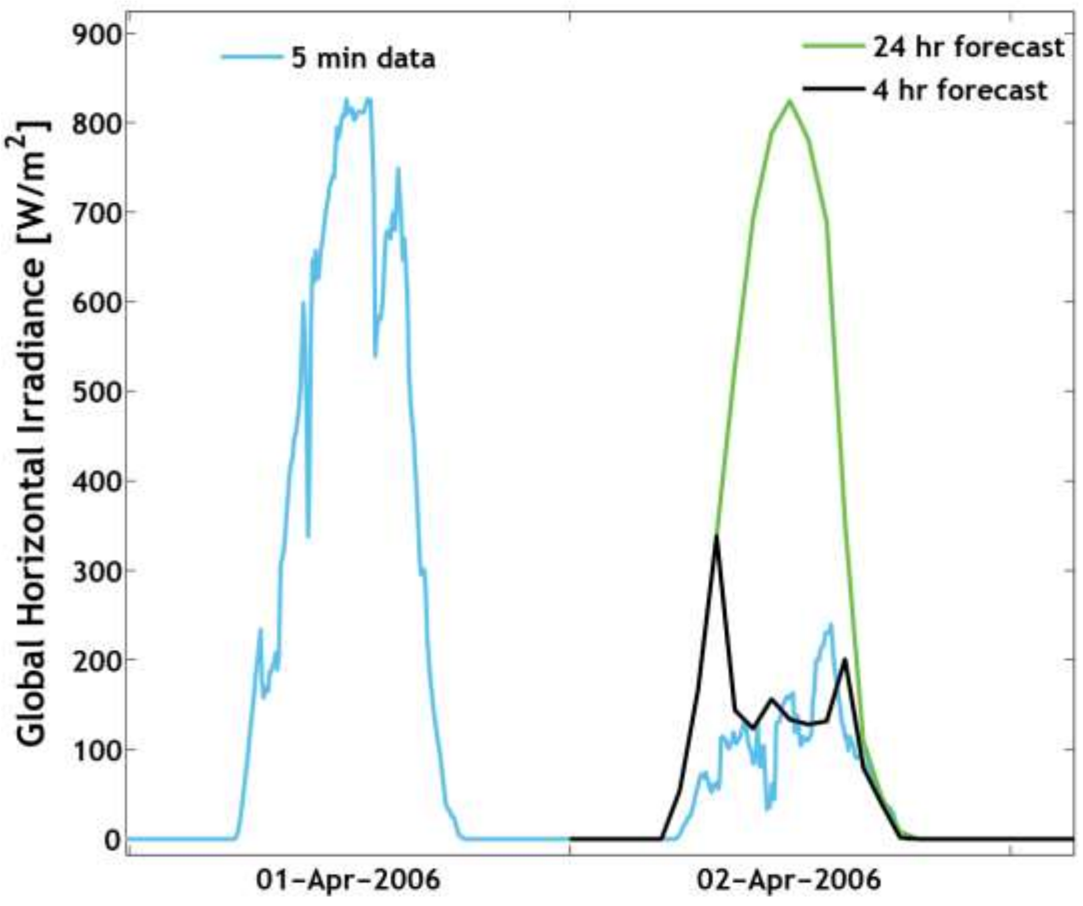
Forecasting Methods: Persistence

Persistence is the "worst case" forecast

24-hour ahead: persistence of the clear power index from the previous day

4-hour ahead: persistence of clear power index from 2-hours before

STATUS: All persistence forecasts are complete.

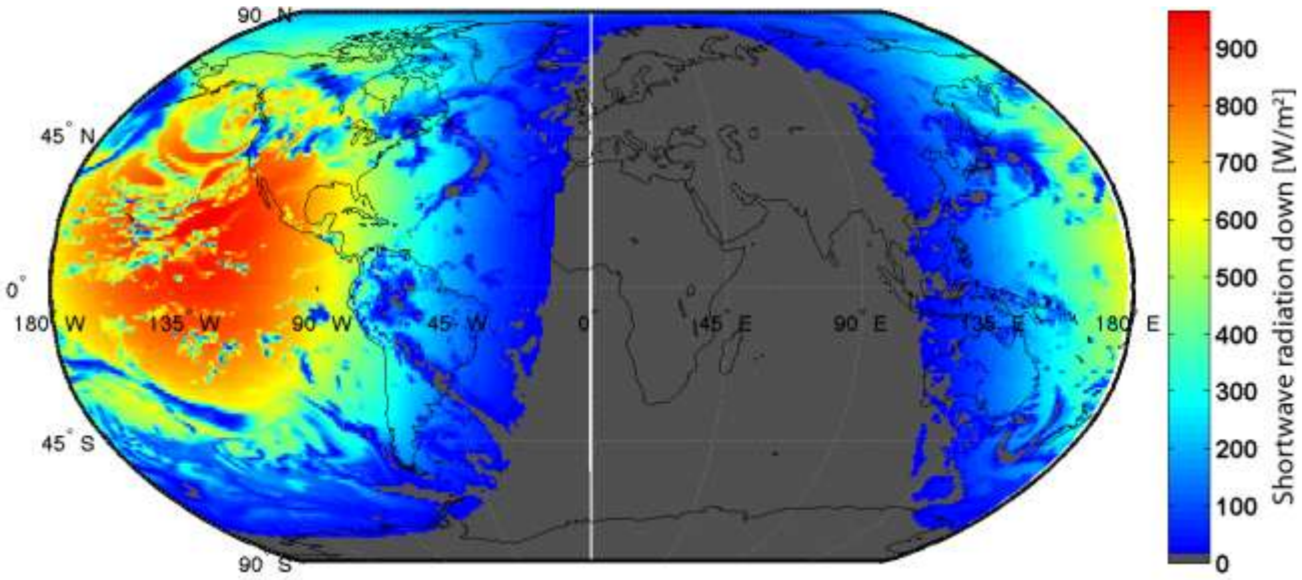


Forecasting Methods: NOAA/NCEP GFS

NOAA/NCEP produces many meteorological forecasts using numerical weather prediction (NWP) models. We use surface radiation forecasts from their Global Forecast System (GFS).

Forecasts are produced every 12 hours:

- forecast points: 03, 06, 09, 12, etc.
- grid: 1°



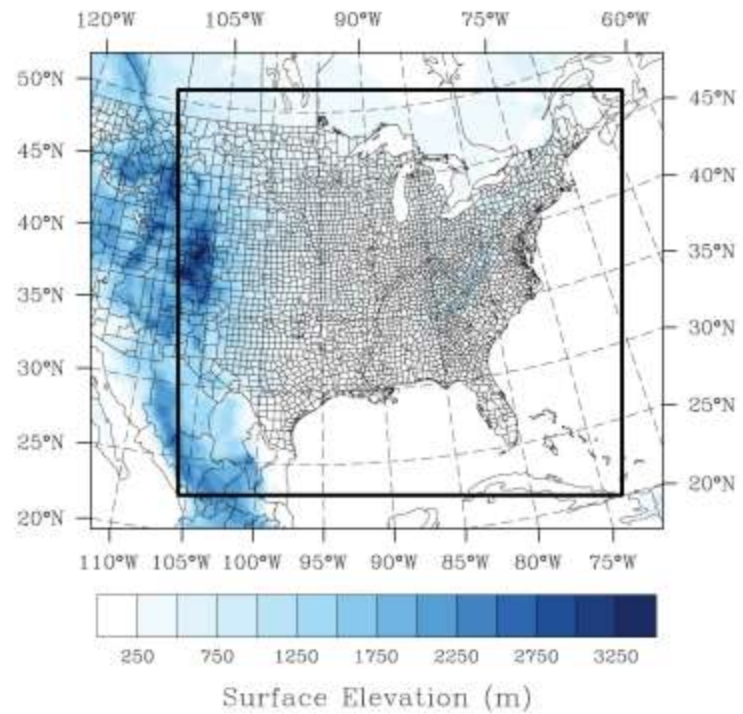
STATUS: Processing GFS data is underway. Final solar power forecast product is expected in December for all ERGIS sites.

Forecasting Methods: WRF

The Weather Research and Forecasting (WRF) model is an open source community NWP model developed by NCAR. We will produce sub-hourly forecasts of DNI, GHI, and DFI.

Forecasts are produced every 6 hours for 38 hours ahead, on a 10 km grid (~0.1°)

STATUS: Tested WRF for 1 week; Final solar power forecast product is expected in December.



WRF modeling domain

NREL's HPC resource: Peregrine

Solar Forecast Plan

- **December: All forecasts will be complete and implemented in PLEXOS**
- **January-February: Forecast error analysis on 24-hour and 4-hour forecasts, by site/region/system, by time of day and season**
- **March: Final report on Solar Forecasts for ERGIS**

Load

Load Data

- **Basis is Ventyx data derived from FERC 714, EIA 861**
  - Checked and scrubbed data source
- **2006 load shapes from Ventyx topology**
- **Ventyx topology mapped onto the ERGIS zones**
- **Scaled to 2025**
- **5 minute load synthesized from hourly load**

2025 Scaling

- Based on EIA AEO 2013 early release
- No one set of factors to scale from 2006 to 2025
- Used state retail load data for 2006 through 2011
- Used AEO NEMS EMM growth data for 2011 to 2025
- State scales compounded with EMM growth
- Simple scaling of profiles

Scale Factors

EMM		States (basis of 2006-2011 scales)	Load Weighted increase 2006-2011	2011 - 2025 EMM Increase	Total Increase 2006-2025
FRCC	FRCC	FL	-1.40%	12.48%	11.08%
MRC	East	WI	-1.70%	7.34%	5.64%
MRC	West	ND, SD, NE, MN, IA, WI	4.11%	8.62%	12.73%
NPCC	NYC/Westchester	NY	1.30%	1.07%	2.37%
NPCC	Upstate	NY	1.30%	2.80%	4.10%
NPCC	Long Island	NY	1.30%	-0.44%	0.86%
NPCC	Northeast	MA, CT, VT, NH, ME, RI	-2.80%	5.85%	3.05%
RFC	East	PA,WV,DE,MD	0.78%	6.47%	7.25%
RFC	Michigan	MI	-2.70%	5.25%	2.55%
RFC	West	OH, IN	0.57%	7.45%	8.02%
SERC	Central	TVA, TN, KY	-1.25%	15.02%	13.77%
SERC	Delta	LA, AR, MO	6.03%	12.07%	18.10%
SERC	Gateway	IL	0.30%	5.63%	5.93%
SERC	Southeast	GA, AL, MS	0.83%	14.40%	15.23%
SERC	VACAR	VA, NC, SC	2.39%	14.38%	16.77%
SPP	North	KS, MO	2.67%	6.91%	9.58%
SPP	South	OK, TX	9%	11.80%	20.80%

Summary of Load Profiles

2006 US EI Profiles	2913	TWh
Scaled US EI Profiles to 2025	**3238**	**TWh**
Average US EI Load Growth 2006 to 2025	11.14%	
Average Annual Load Growth	0.56%	

Region	2025 Load (TWh)	Peak Load (GW)
FRCC	257	51
HQ	192	35
IESO	156	28
ISO-NE	137	29
MISO	804	152
NBSO	28	5
NYISO	166	35
PJM	915	188
Saskatchewan	22	3
SERC	743	141
SPP	242	50

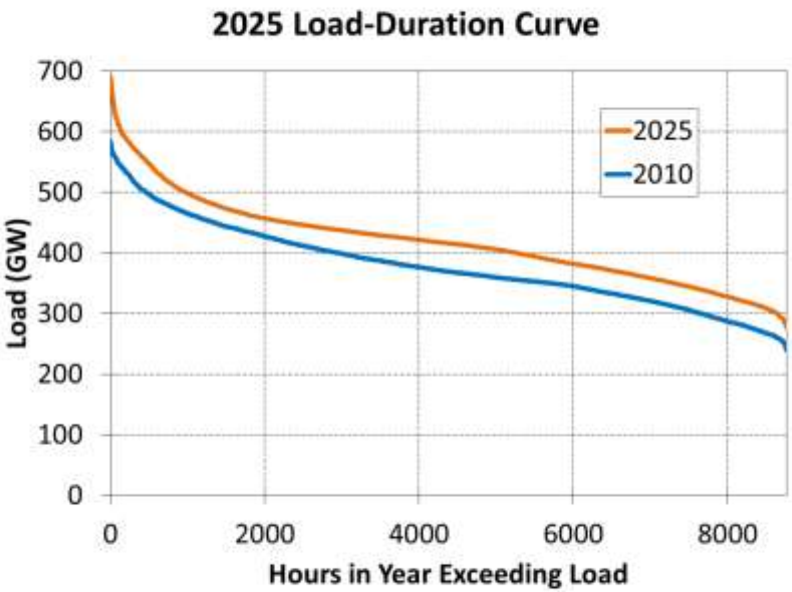
High-Resolution Load Synthesis

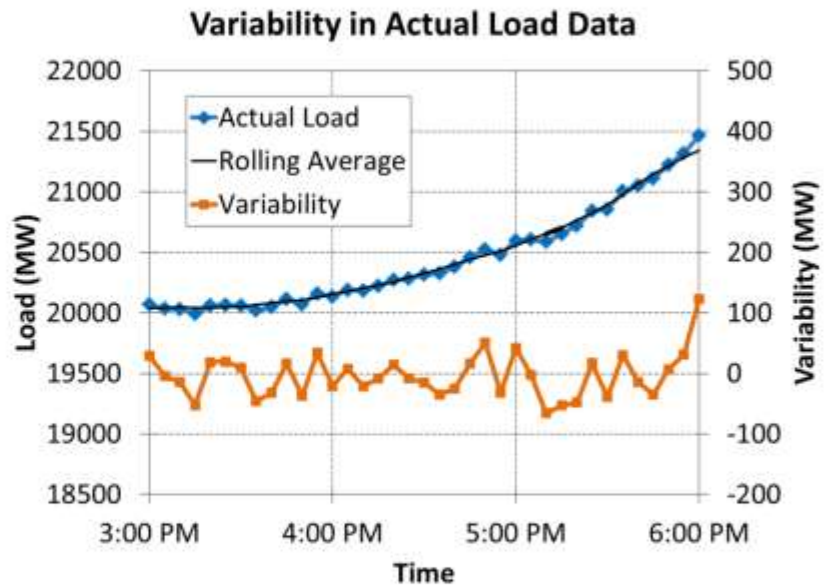
- Use recorded high-resolution load data to understand the intra-hour variability then apply that to hourly study hourly profiles
- Detailed analysis of a number of high resolution datasets obtained online and provided by the TRC
- Goal was to separate the high resolution variability from the underlying trend
- A number of filters were tried
- 45 minute moving average window performed the best at separating the variability from the trend

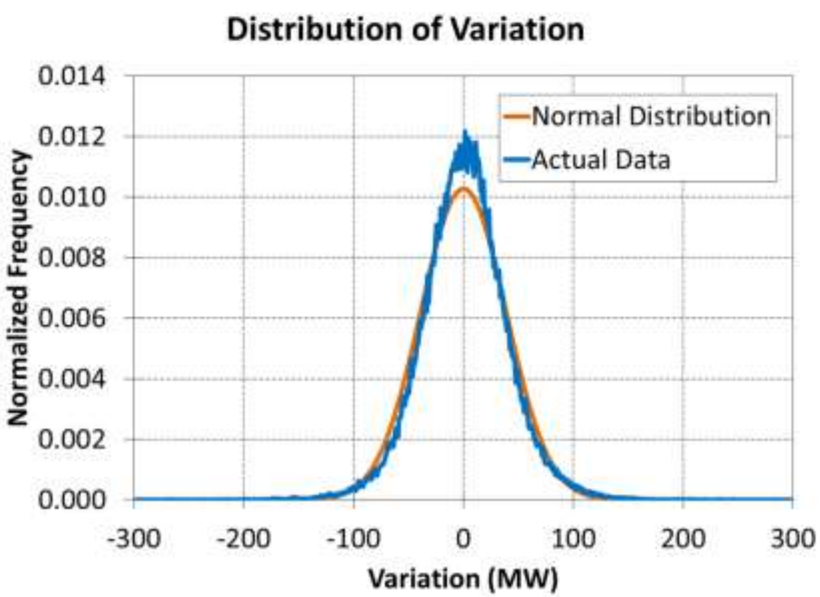
High Resolution Load Data Sources

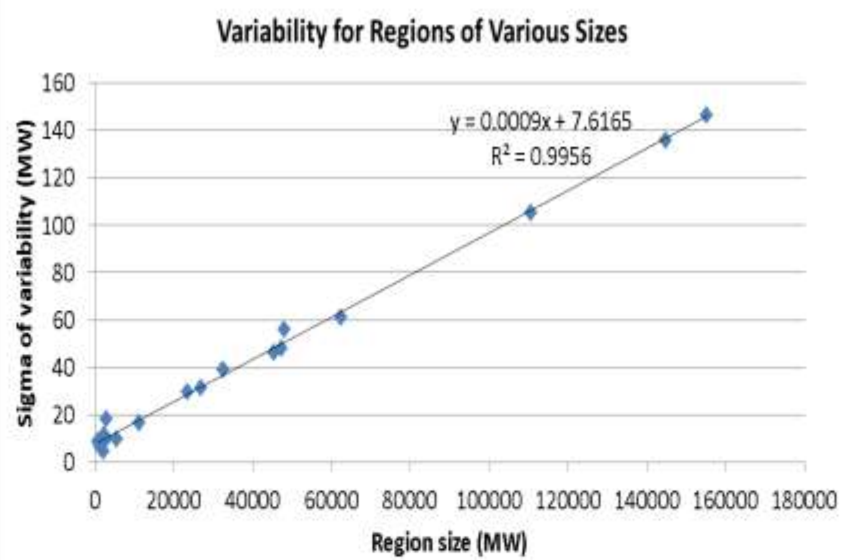
Region	Period	Resolution	Comment
		EWITS	
ISO-NE	2005	1 minute	
MISO	2005	10 Minute	
NYISO	2005	10 Minute	by region
PJM	2005 and 2006	10 minute	by region
SoCo	2005	10 Minute	
SPP	2005-2006	1 minute	
		New Data	
ISO-NE	part 2013	5 minute	3 months
NYISO	2012	5 Minute	by region
PJM	2012	1 Minute	
SPP	2010, 2011 and 2012	5 Minute	

Sub-Hourly Load Data for 2025



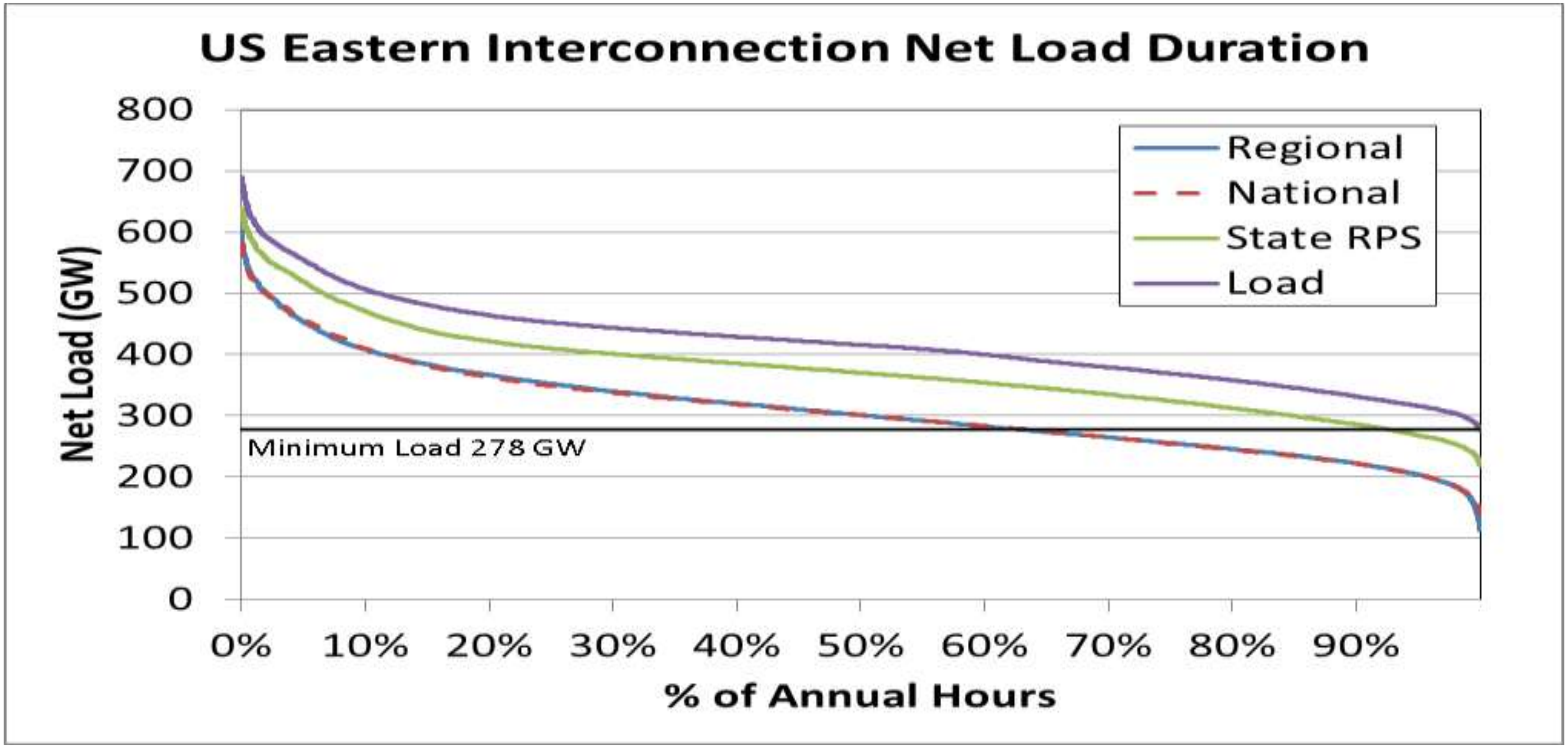






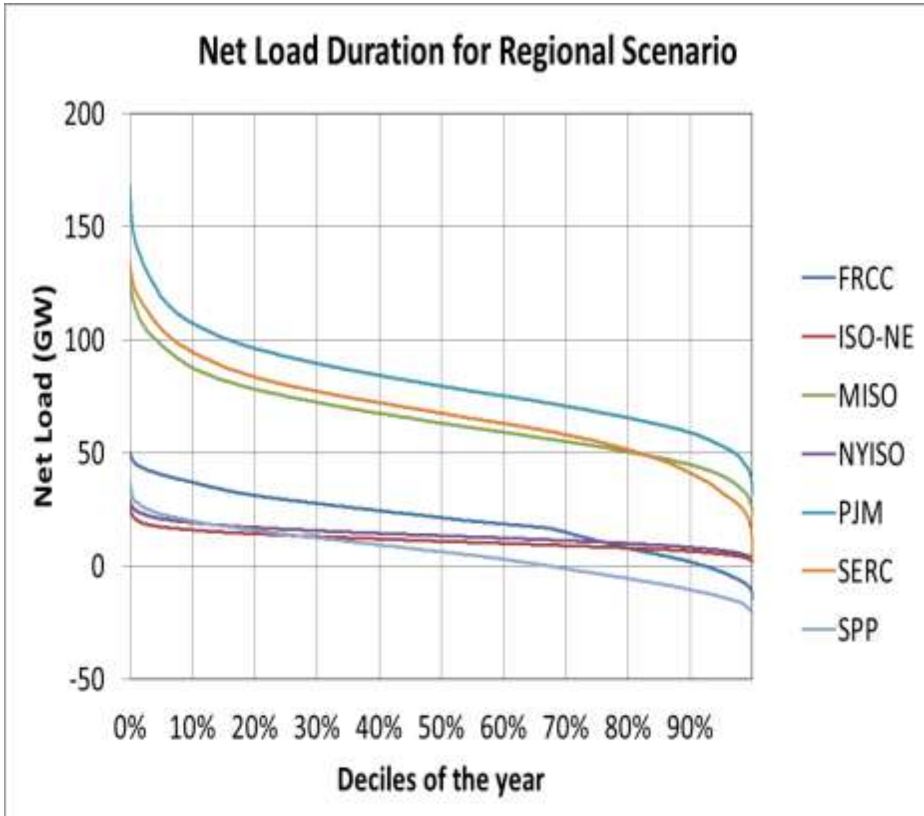
Net Load

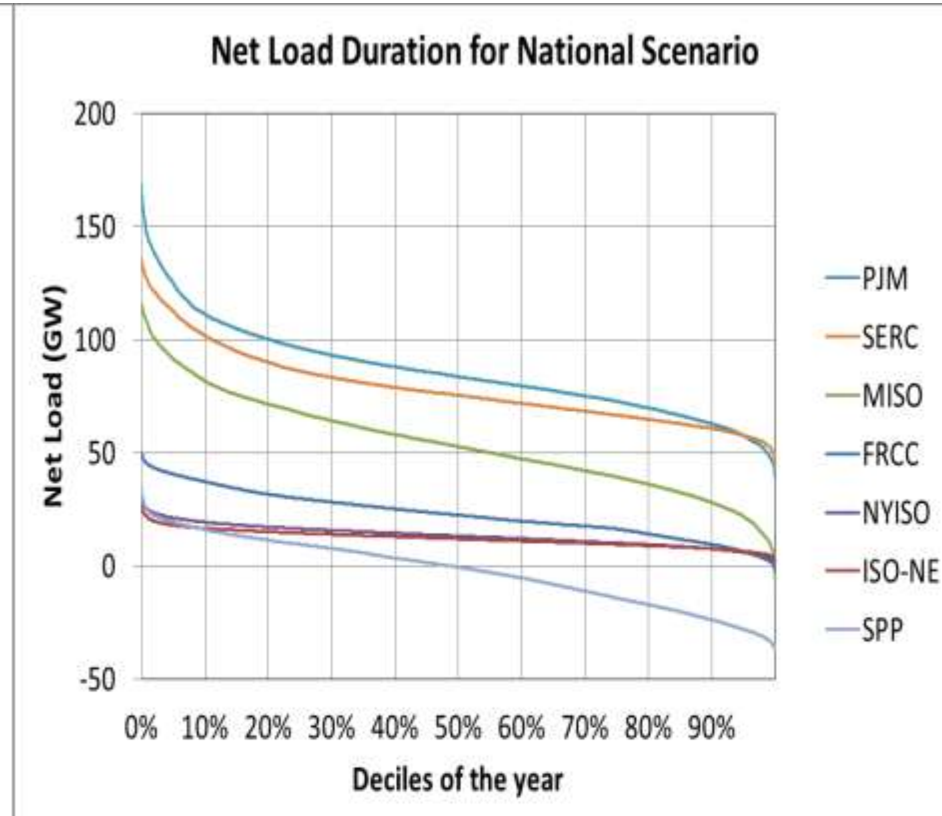
- Regional and National scenarios are nearly identical
- Expected differences even though the energy is the same
- Shift of energy between regions and resources does not have an effect on the tails
- No periods of negative net load, but minimum of approx. 100 GW
- Net load is less than gross minimum load about 33% of the time



Regional Net Load Duration

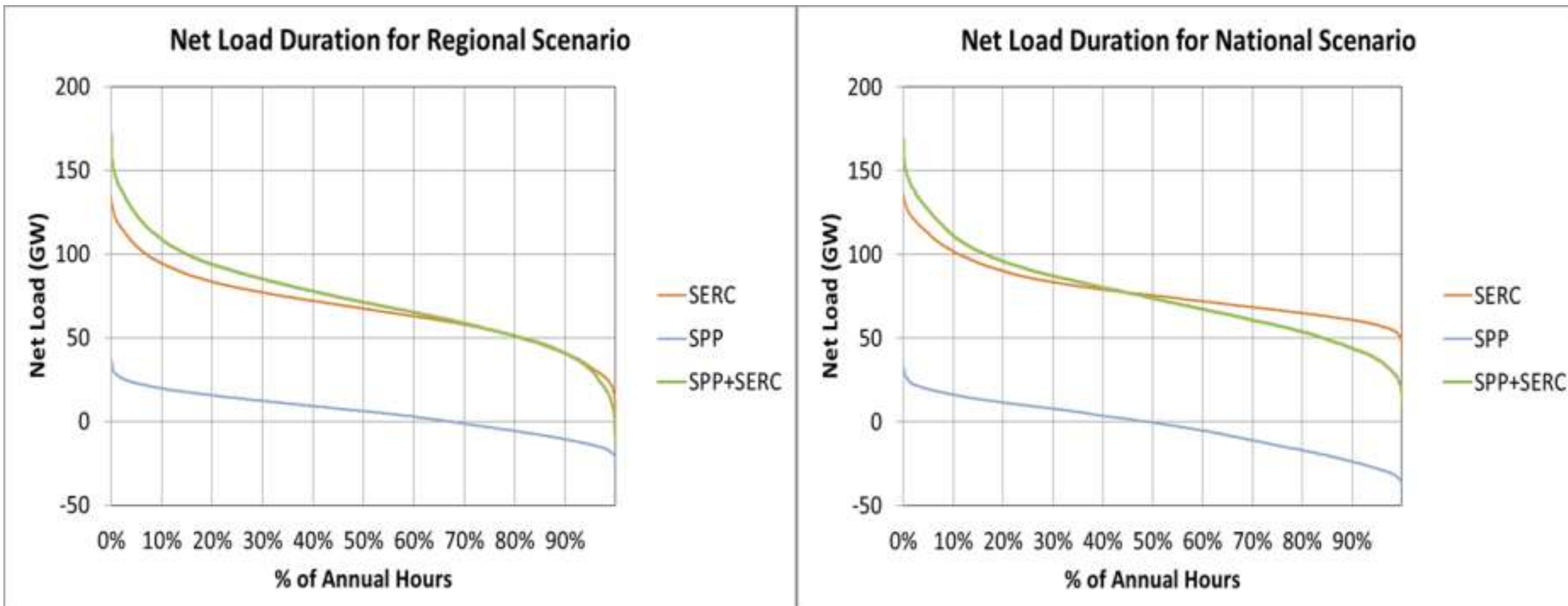
- Significant number of hours of negative net load for SPP and FRCC (Regional), SPP (National)
- SPP is exporting large amounts of VG to SERC





SPP/SERC Detail

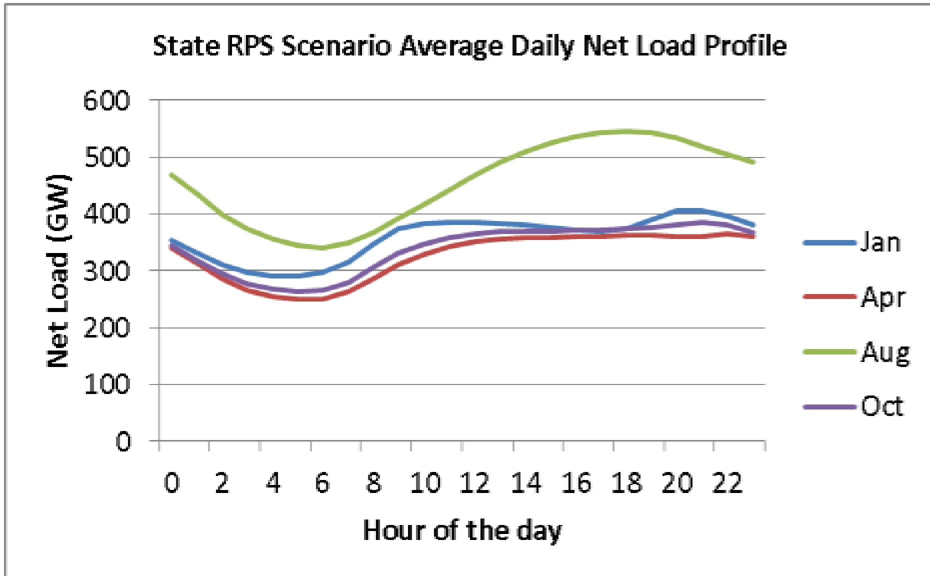
- SPP combined with SERC, total VG penetration is 28%
- SERC dominates with more than double the load of SPP
- For combined SPP+SERC, only a few negative net load hours in the Regional Scenario, none in National Scenario

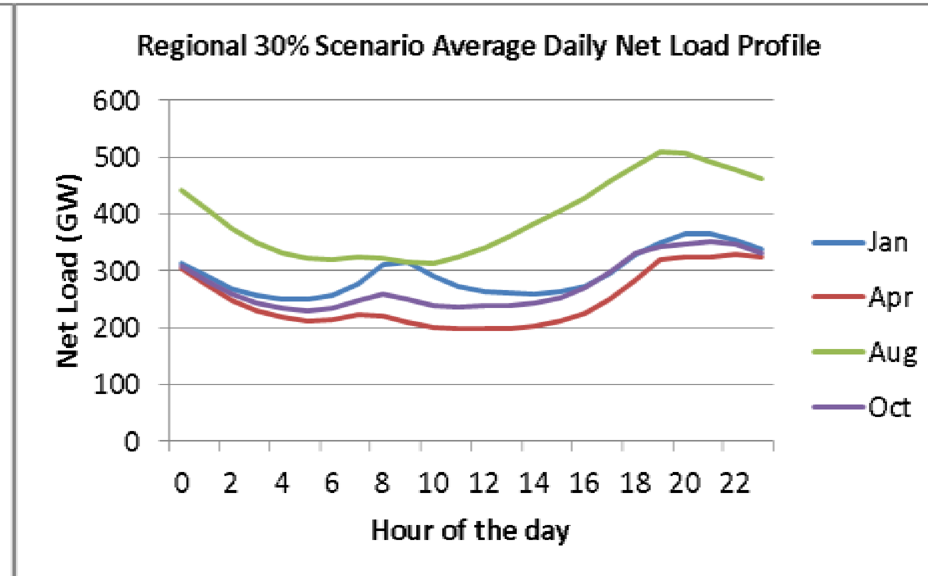


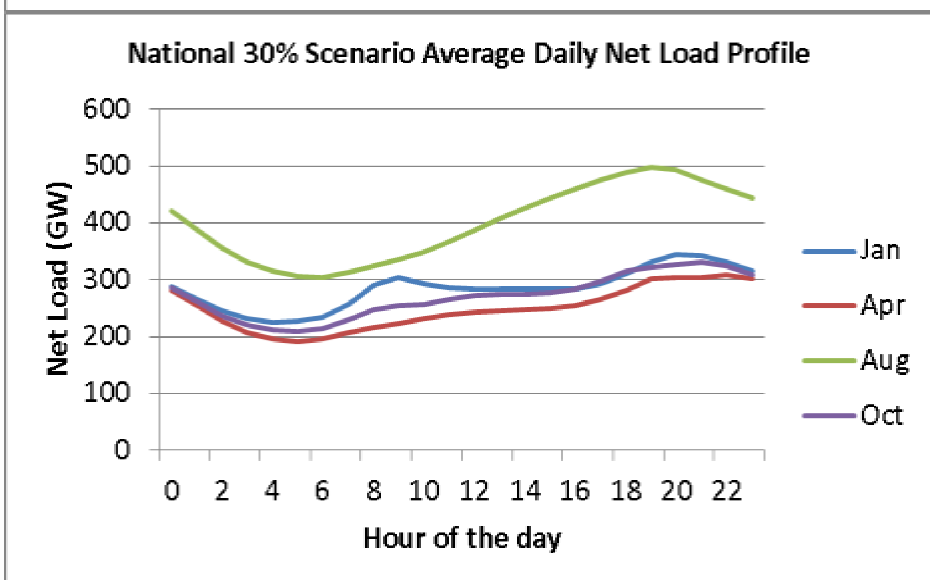
Net Load Ramping Data

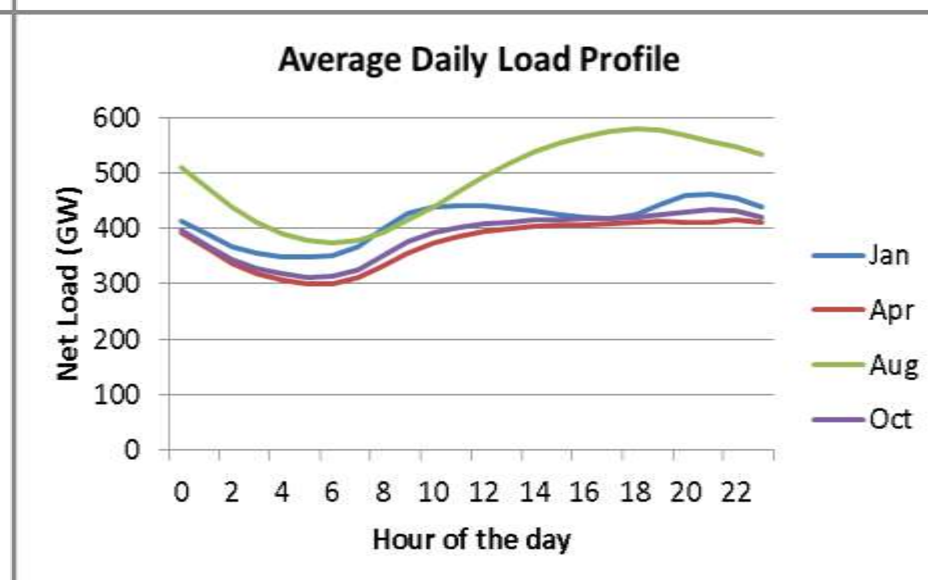
	FRCC	ISO-NE	MISO	NYISO	PJM	SERC	SPP	All US EI
Sigma (MW/Hour)								
Load-alone	1778	867	3370	871	4161	3623	1138	14953
State RPS Scenario	1778	911	3633	991	4200	3629	1660	15325
Regional Scenario	1957	948	3753	985	4411	3747	2164	15509
National Scenario	1880	928	4265	1018	4370	3622	2808	16062
Max Neg Delta (MW/Hour)								
Load-alone	-6936	-2697	-10880	-2805	-12692	-9630	-3281	-42348
State RPS Scenario	-6936	-2872	-13339	-3089	-15233	-10044	-6689	-48942
Regional Scenario	-8435	-3189	-14546	-3115	-19032	-10926	-9760	-54369
National Scenario	-7967	-3139	-18152	-3277	-18543	-10195	-13029	-55725
Max Pos Delta (MW/Hour)								
Load-alone	5739	2628	9706	2620	12153	9961	3279	38918
State RPS Scenario	5739	3371	11639	3943	12979	9794	6126	42969
Regional Scenario	7089	3594	12506	3937	14146	12400	8118	47278
National Scenario	6337	3581	16460	4141	14165	9946	11702	48086
No. Drops < 3 * Load Sigma								
Load-alone	2	1	1	2	2	0	0	0
State RPS Scenario	2	6	6	13	4	0	189	1
Regional Scenario	9	20	15	14	11	1	503	2
National Scenario	6	8	55	19	9	0	946	3
No. Rises > 3* Load Sigma								
Load-alone	1	2	0	1	0	0	0	0
State RPS Scenario	1	38	14	89	1	0	180	0
Regional Scenario	34	70	29	76	26	2	519	5
National Scenario	7	59	129	99	26	0	939	13

Average Net Load Profiles

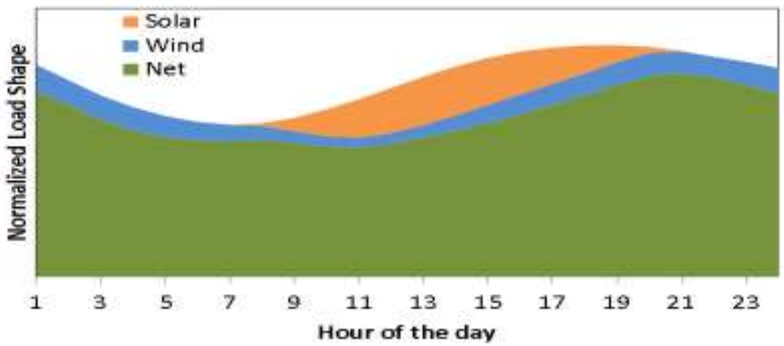
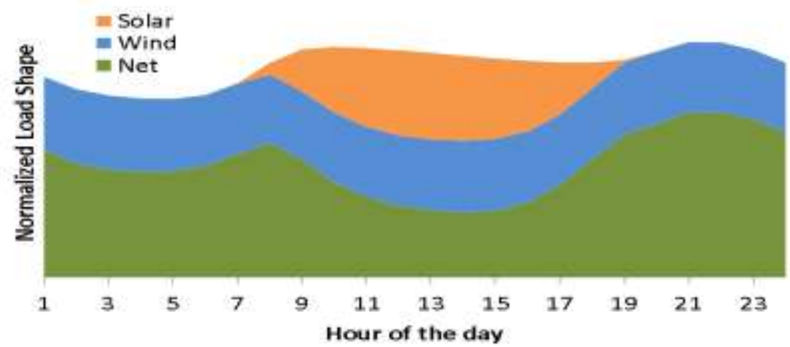
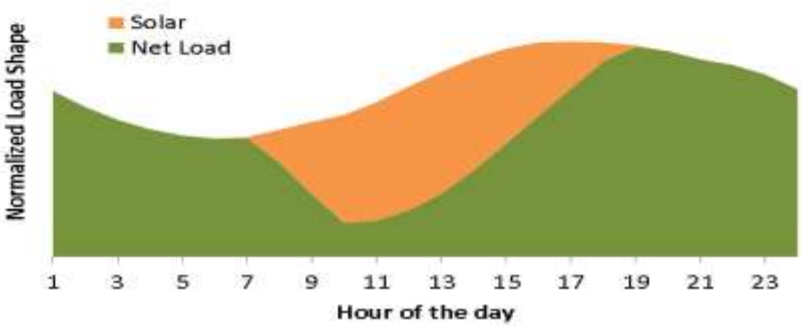
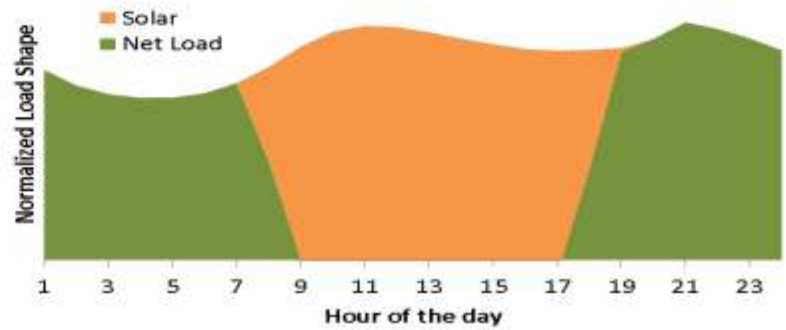
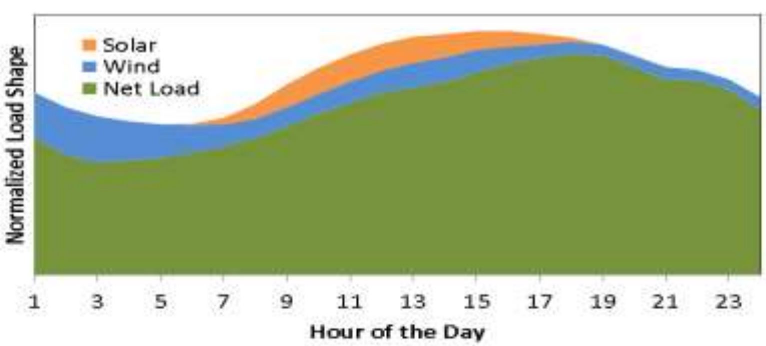
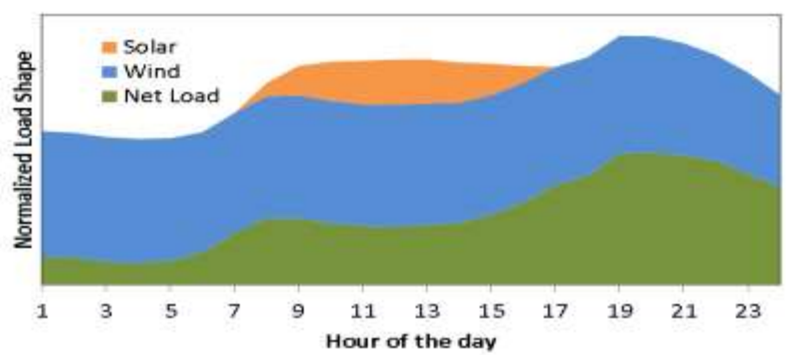




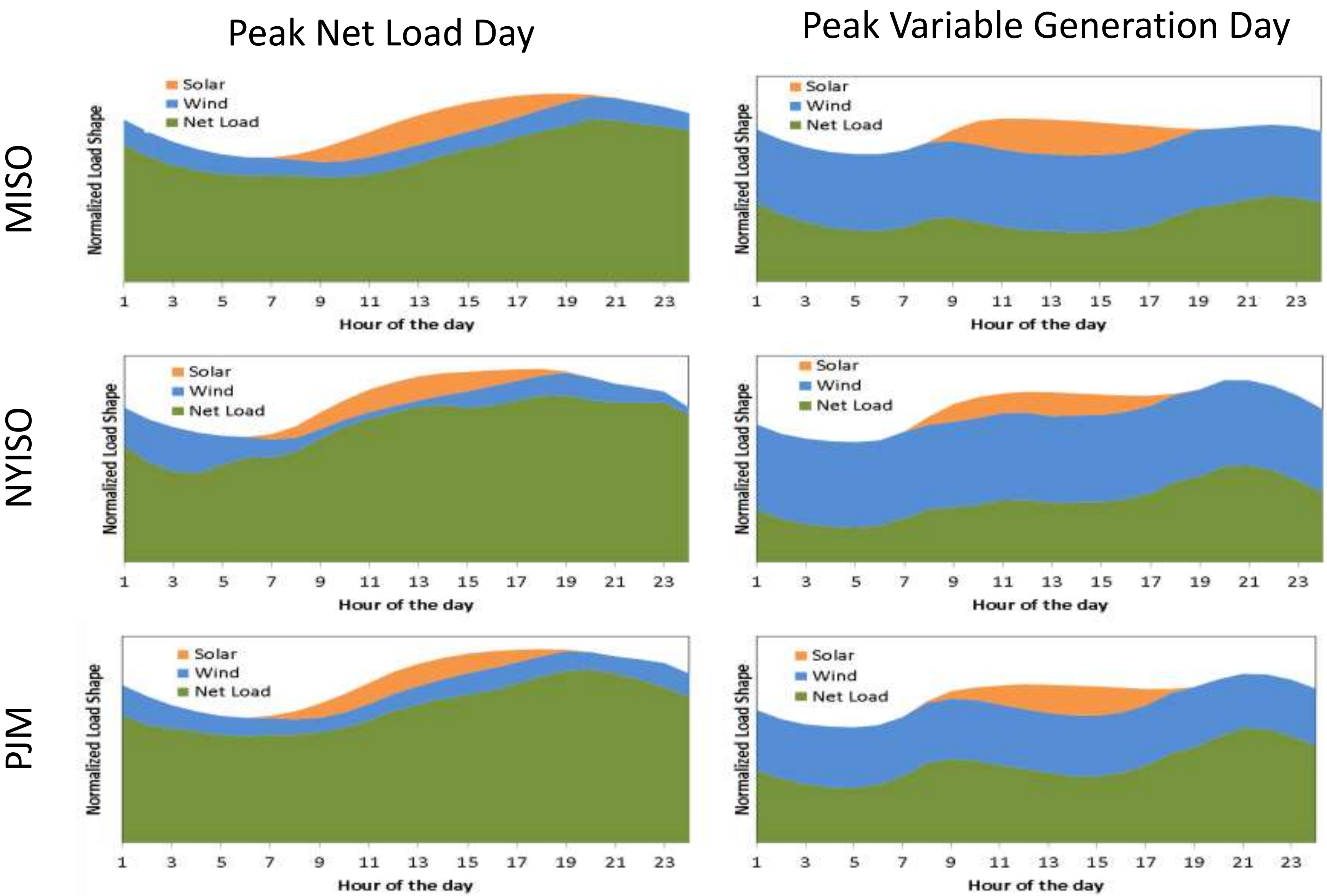




Net Load Profiles for Selected Regions

	Peak Net Load Day	Peak Variable Generation Day
Entire US EI		
FRCC		
ISO-NE		

Net Load Profiles for Selected Regions

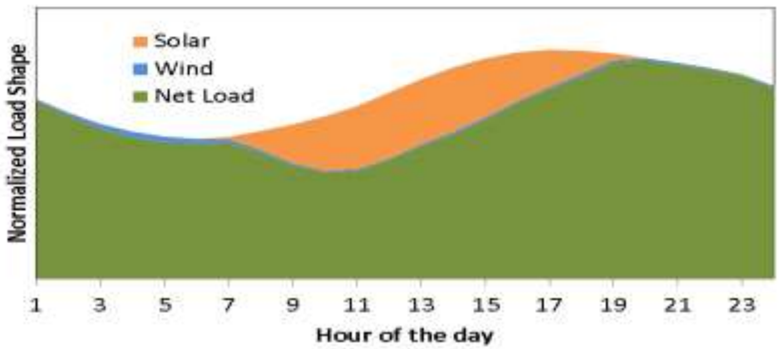


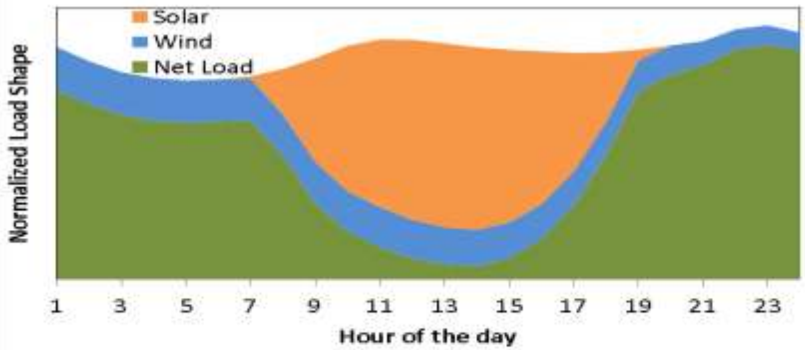
Net Load Profiles for Selected Regions

Peak Net Load Day

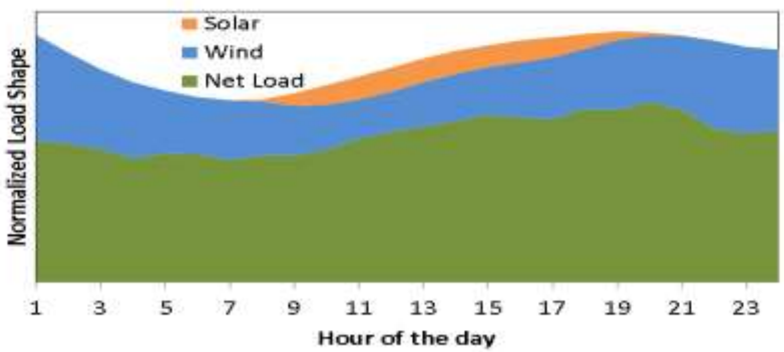
Peak Variable Generation Day

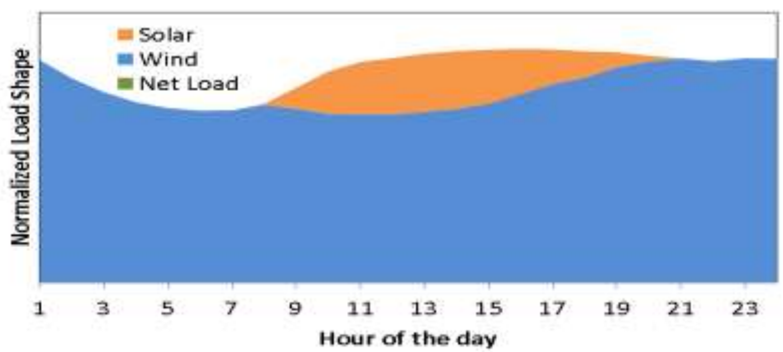
SERC

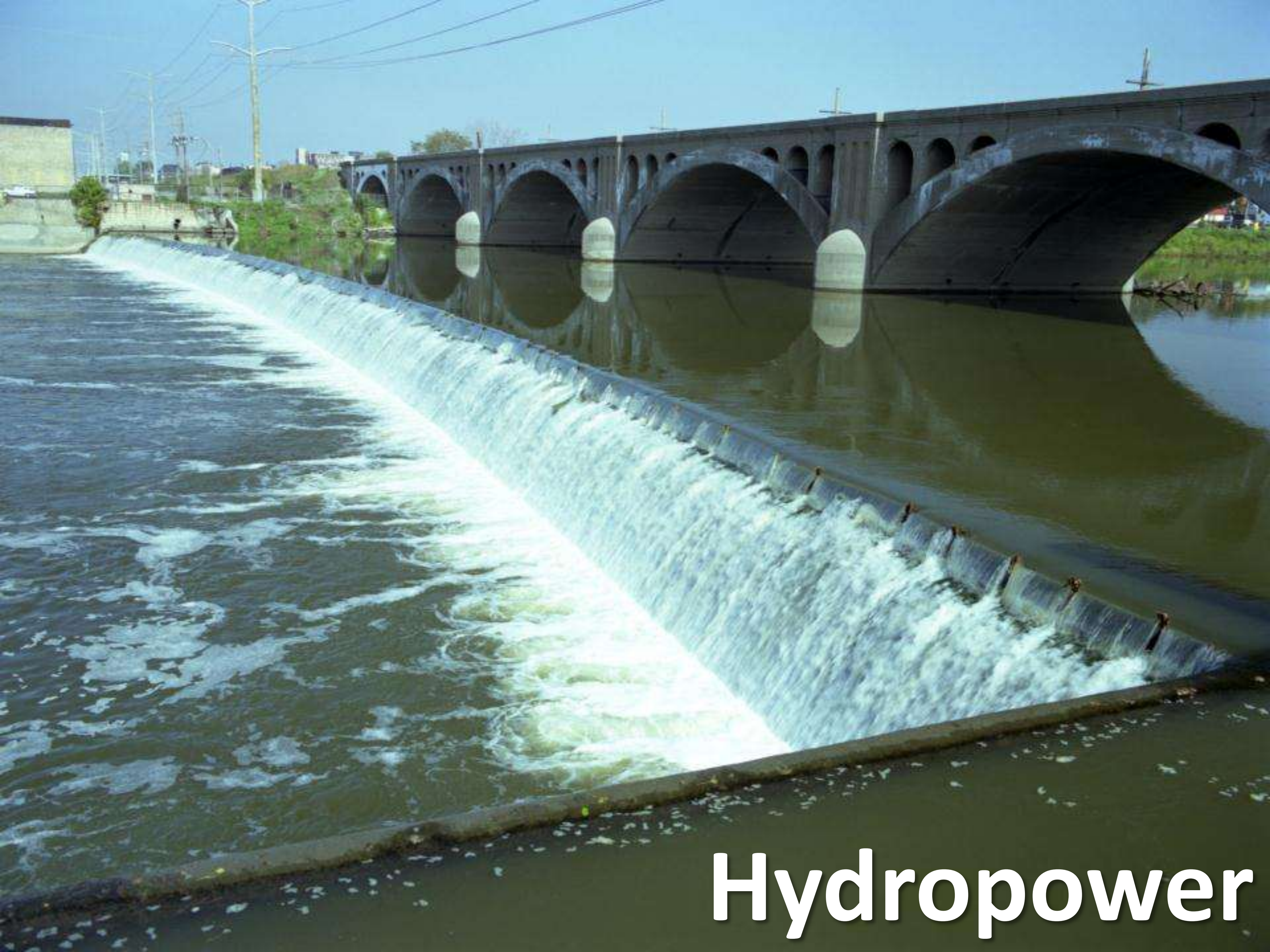




SPP






Hydropower

Eastern Interconnection Hydro Facts

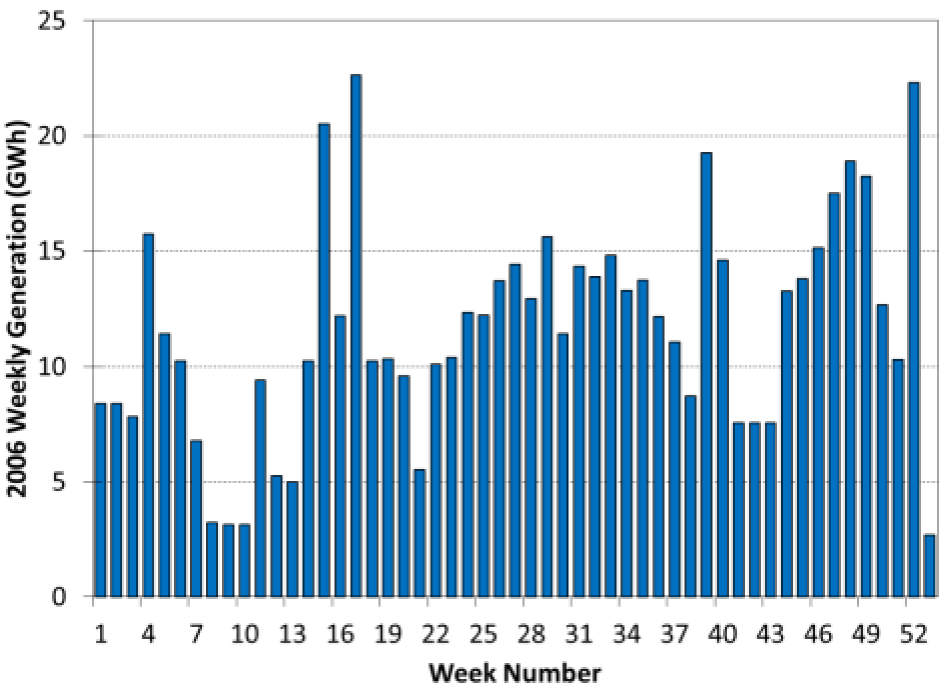
- **Federal US Hydro**
  - Southwestern Power Administration
    - Nameplate Capacity: 2,174 MW
  - Southeastern Power Administration
    - Nameplate Capacity: 3,392 MW
  - Tennessee Valley Authority
    - Nameplate Capacity: 4,051 MW
- **Canadian Hydro**
  - Manitoba
    - Nameplate Capacity: 5,909 MW
  - Ontario
    - Nameplate Capacity: 7,518 MW
  - Quebec
    - Nameplate Capacity: 48,498 MW
- **Rest of EI**
  - Nameplate Capacity: 20,838 MW
- **Total EI Hydro**
  - Nameplate Capacity: 92,780 MW

Hydro Generator Limits

- **Hydro generators have very low marginal cost but limited water availability**
- **Hydro is 10% of total installed capacity in EI and much higher in some regions**
- **Constraints must be created to limit hydro generation to realistic levels**
- **Four levels of hydro generator limit confidence:**
  - Actual daily or weekly historical generation (SEPA, SWPA, USACE facilities)
  - Actual monthly historical generation EIA-923 (other US hydro)
  - Annual historical generation and flow data (MB, NB, ON)
  - Estimated annual historical generation and flow data (QC, SK)

Example: SEPA, SWPA, or USACE Facility

- **Worked with SEPA, SWPA, and USACE to obtain actual historical generation down to daily resolution**
- **Example: Wolf Creek Dam**
  - Kentucky, 210 MW
  - Annual capacity factor ~33%;
  - Weekly minimum capacity factor ~7%
  - Weekly maximum capacity factor 64%



Example: Manitoba Hydro

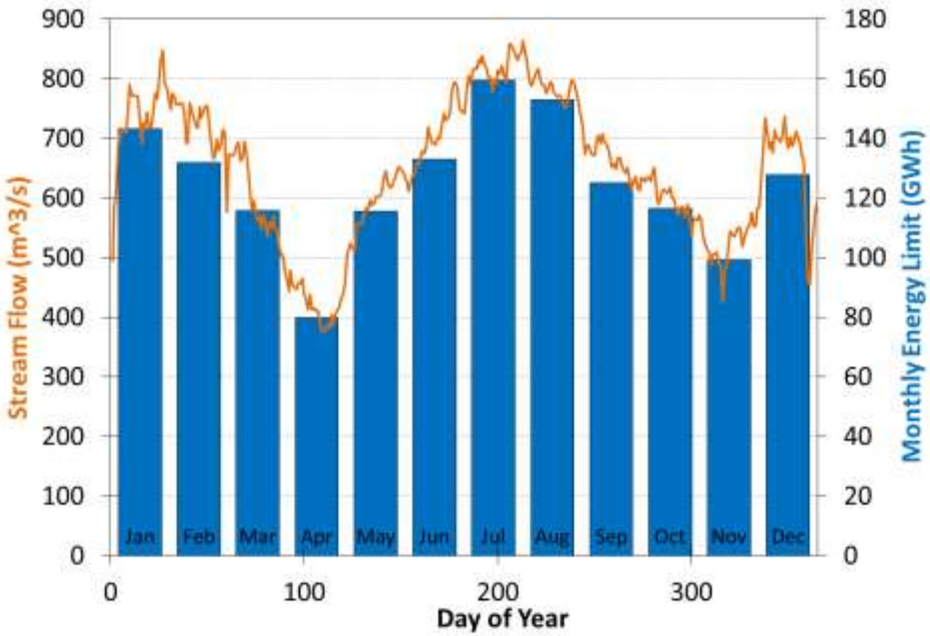
- **Calculate energy limits based on annual energy generation and monthly or daily flow data**

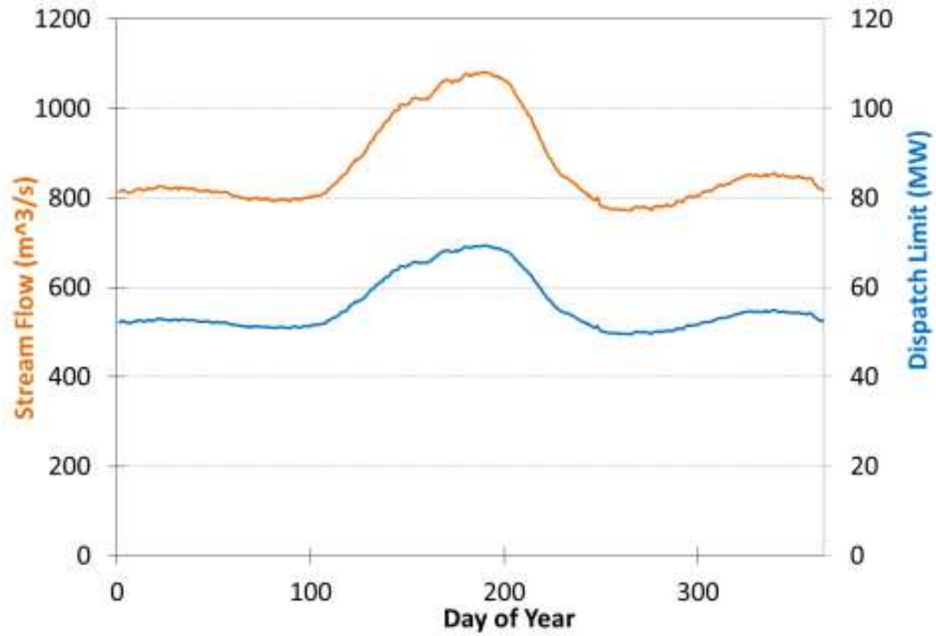
- **Monthly Limits**

$$Limit = \sum_{year} generation \times \frac{\sum_{month} flow}{\sum_{year} flow}$$

- **Daily Dispatch Limits**

$$Limit = \sum_{year} generation \times \frac{\sum_{day} flow}{\sum_{year} flow} \times \frac{1}{24}$$





Thermal Expansion

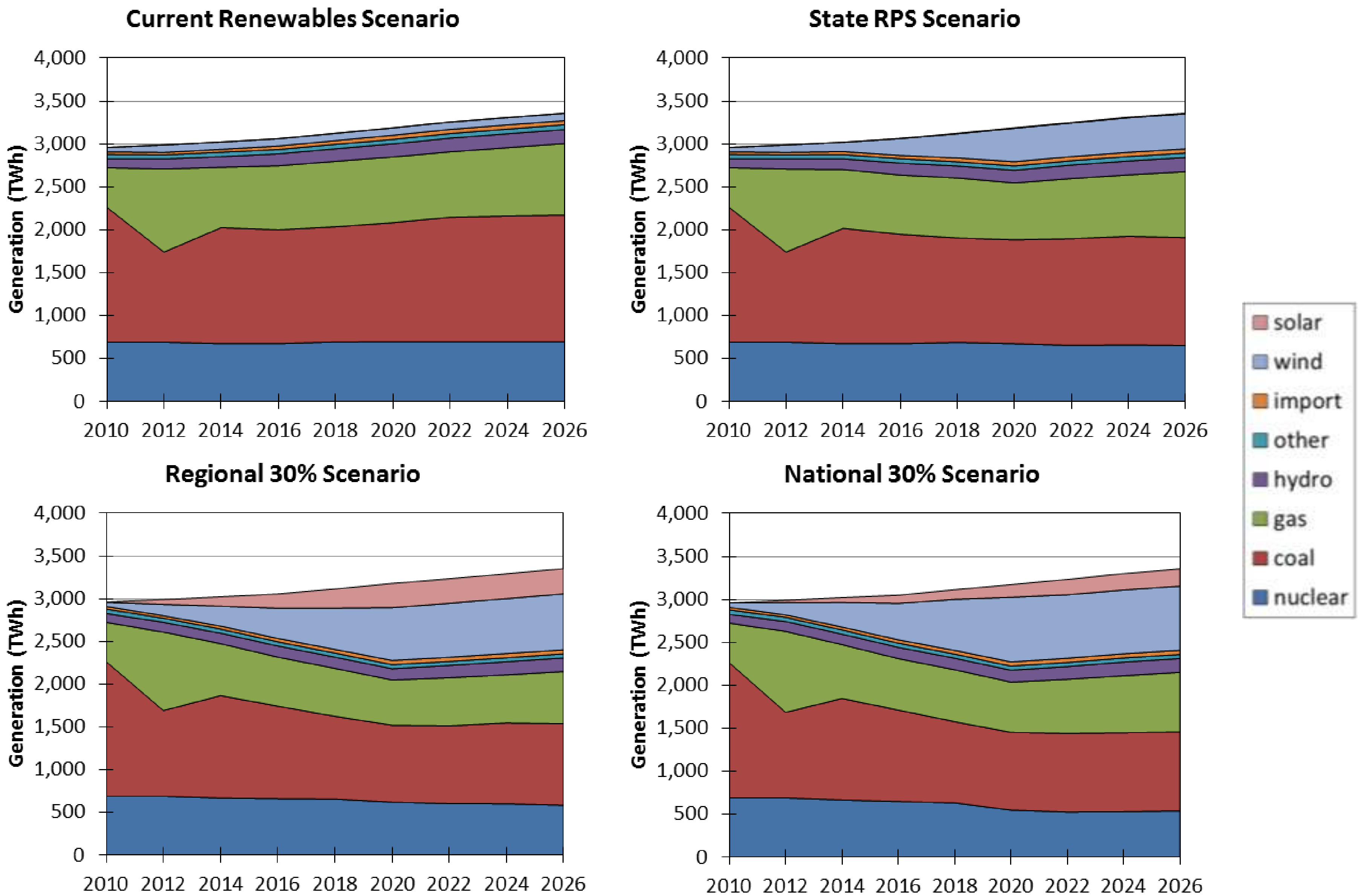
Wind and Solar Scenarios

- **Current Renewables**
  - 3% wind
- **State-RPS Renewables**
  - 12% wind, 0.25% solar
- **30% Penetration, Regional**
  - 20% wind, 10% solar
- **30% Penetration, National**
  - 25% wind, 5% solar

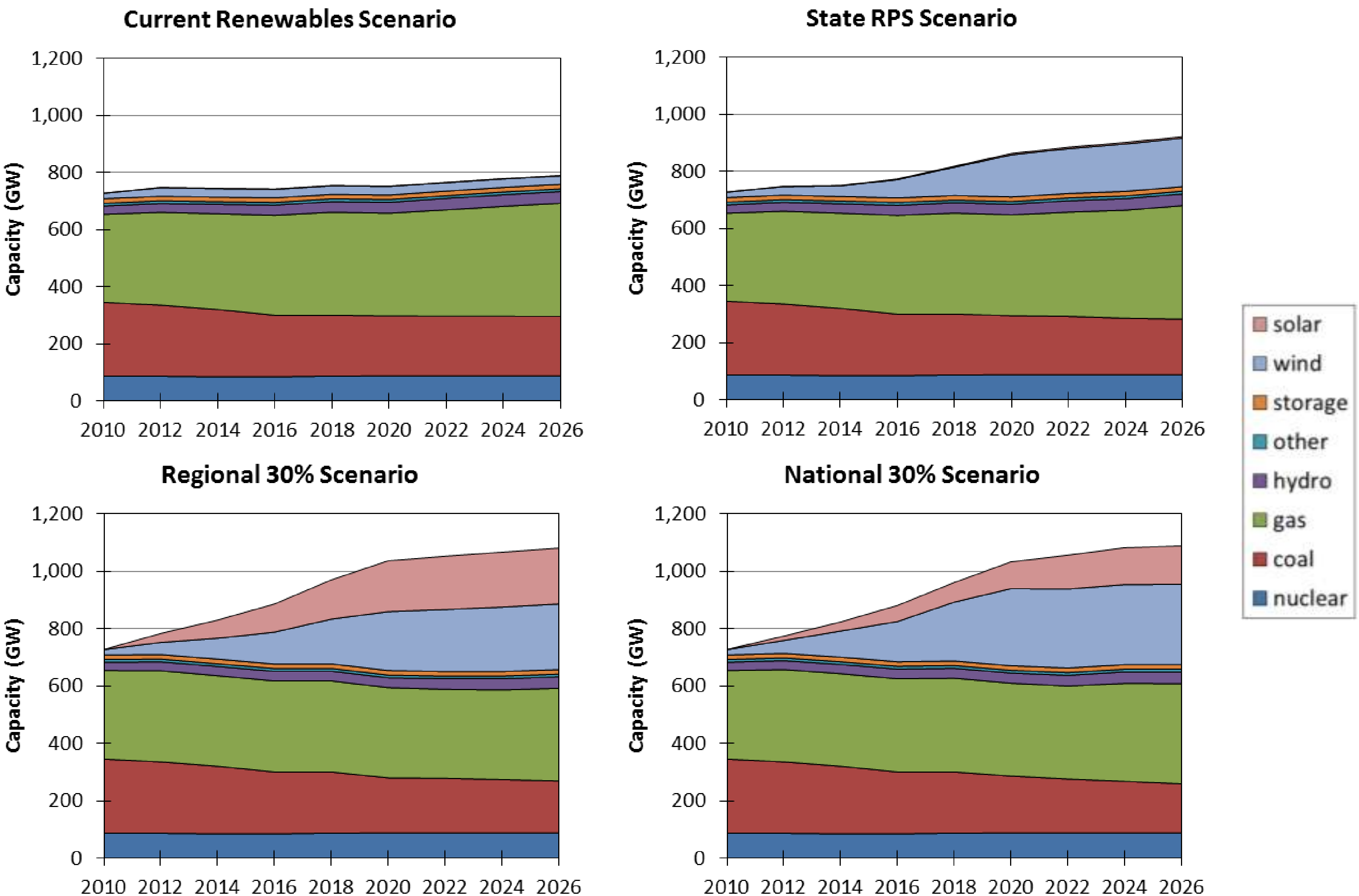
Capacity Expansion

- **Regional Energy Deployment System (ReEDS)**
  - Long-term capacity-expansion model
  - Aims to minimize total system costs
    - Constraints include: transmission, load, reserves
  - Multi-regional (356 wind/solar resource regions, 134 balancing areas)
  - Temporal resolution: 17 time slices in each year
  - Identifies energy requirement for ReEDS region

Results: Generation by Type

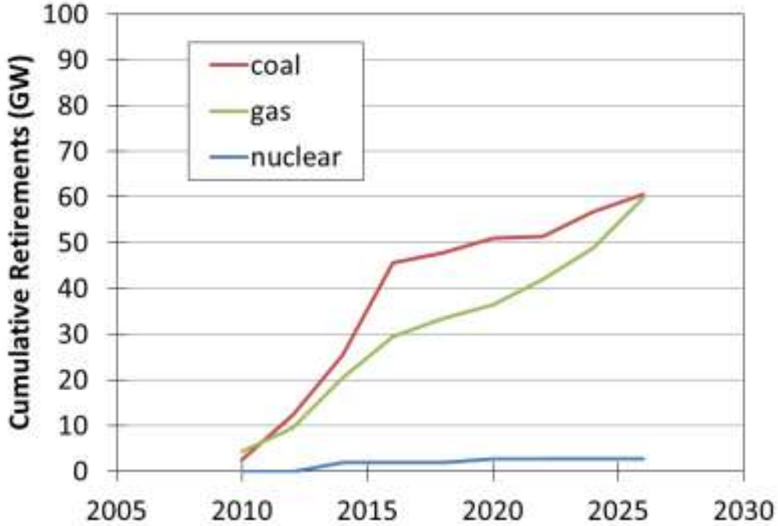


Results: Installed Capacity by Type

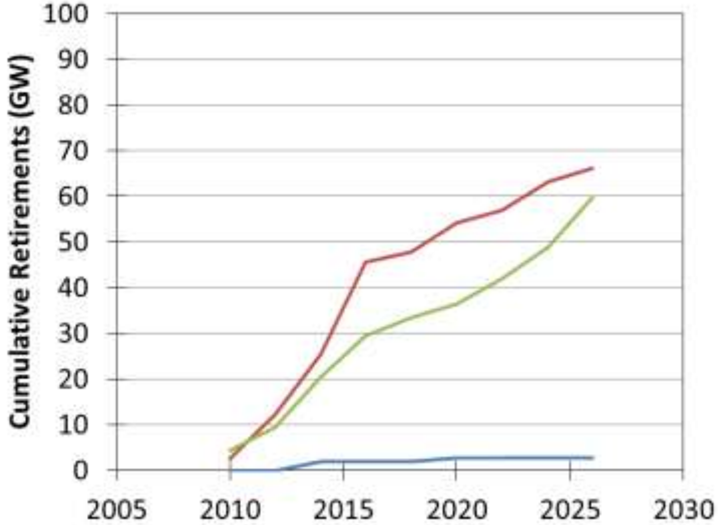


Results: Retirements by Fuel

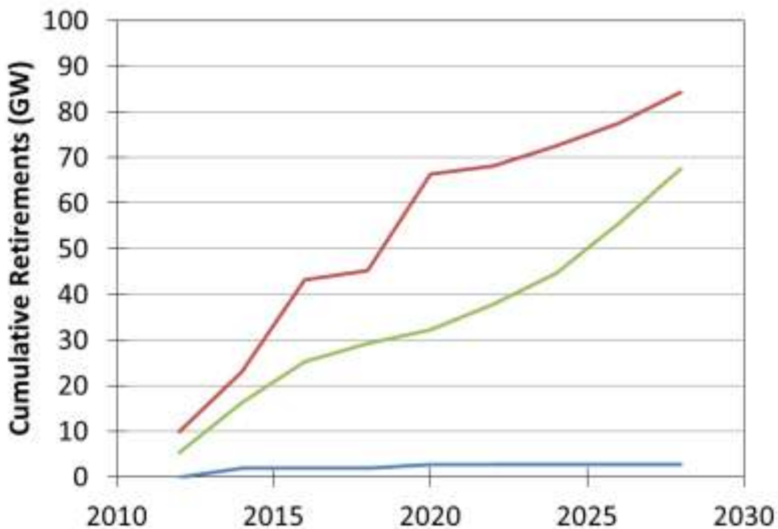
Current Renewables Scenario



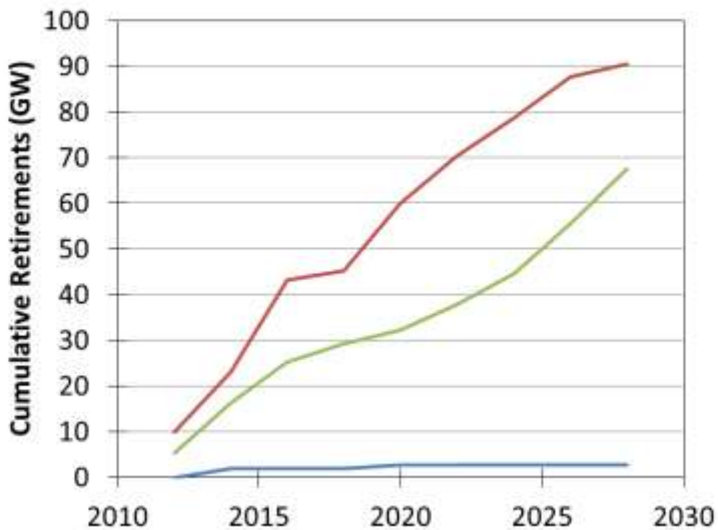
State RPS Scenario



Regional 30% Scenario



National 30% Scenario

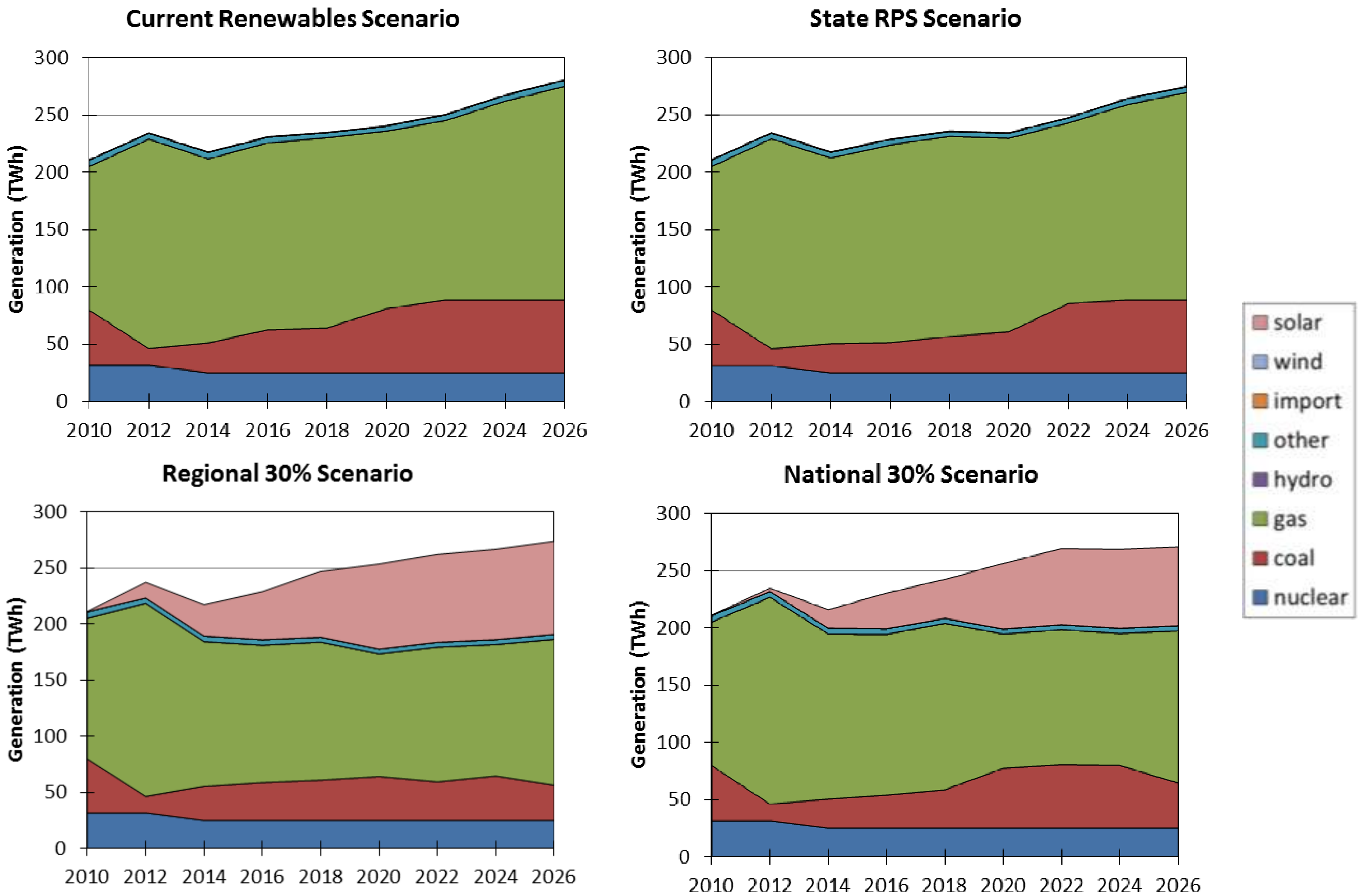


Results: Installed Capacity

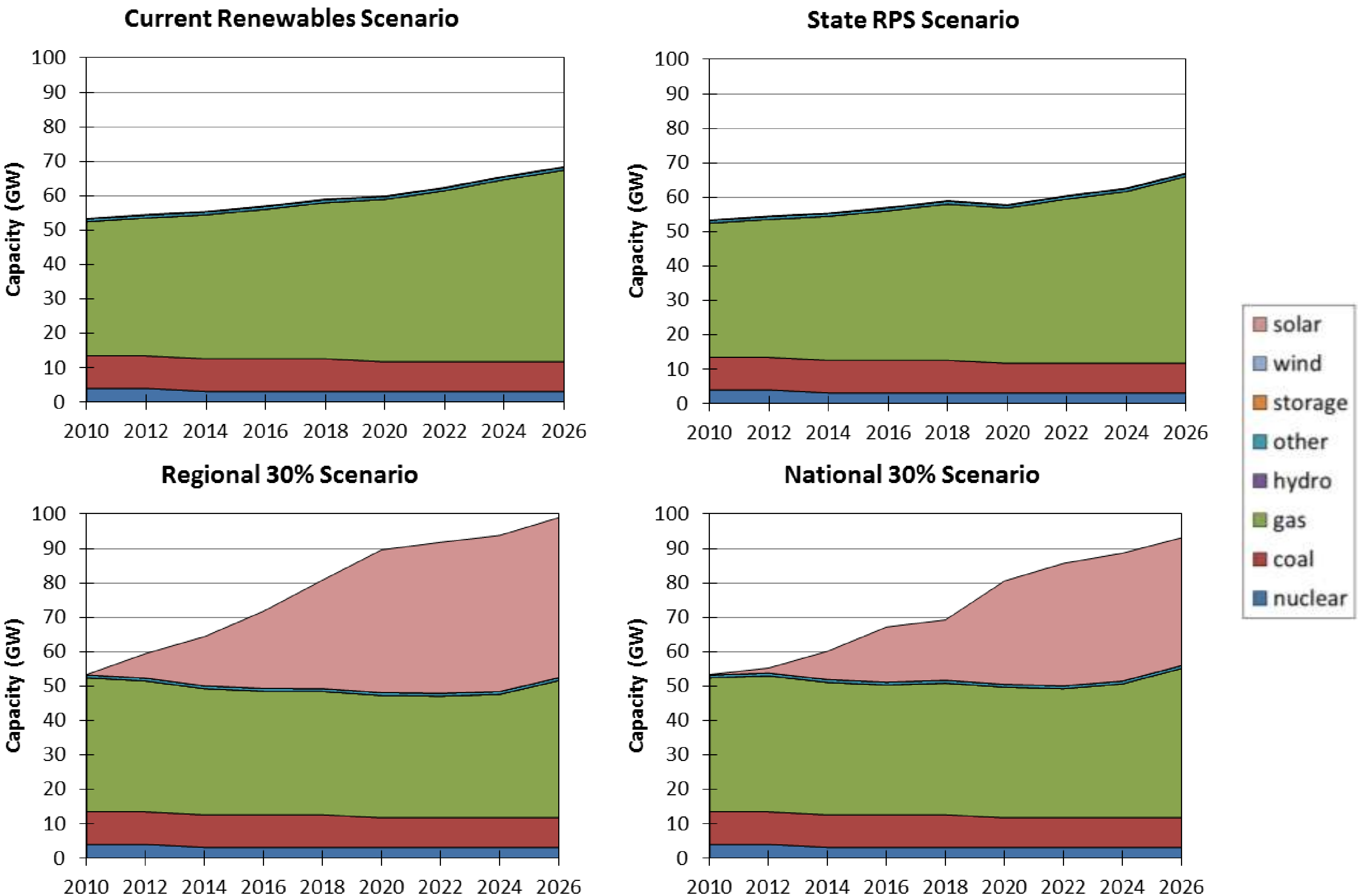
Year	Scenario	Installed Capacity (GW)						
		Nuclear	Coal	Gas	Hydro	Wind	Solar	Other
2010	All	87	259	309	29	19	0	25
2025	A	88	209	391	41	30	1	25
	B	88	197	389	41	168	5	25
	C	88	184	318	39	227	193	25
	D	88	176	346	40	279	131	25

Regional Results

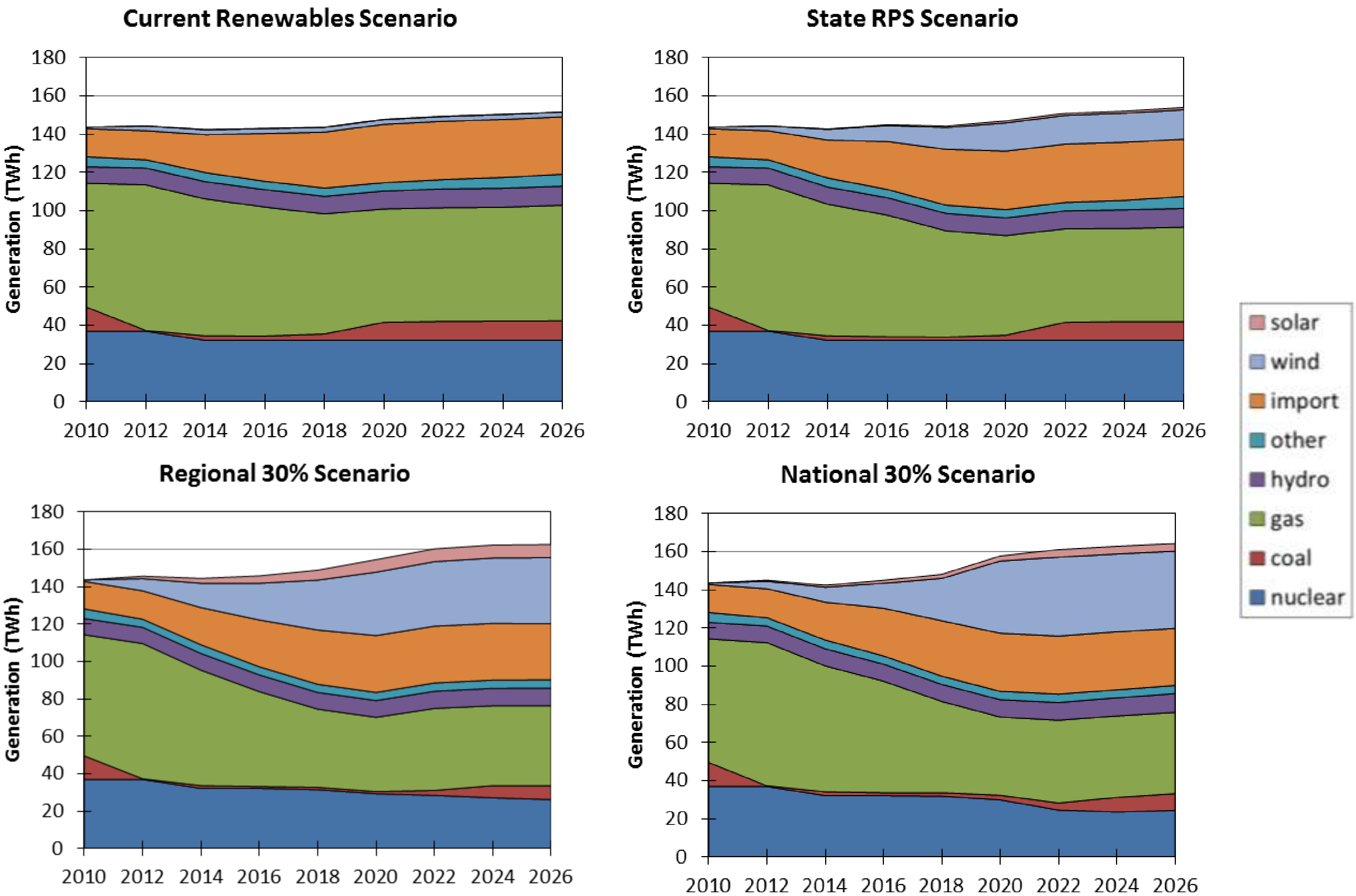
FRCC Generation by Type



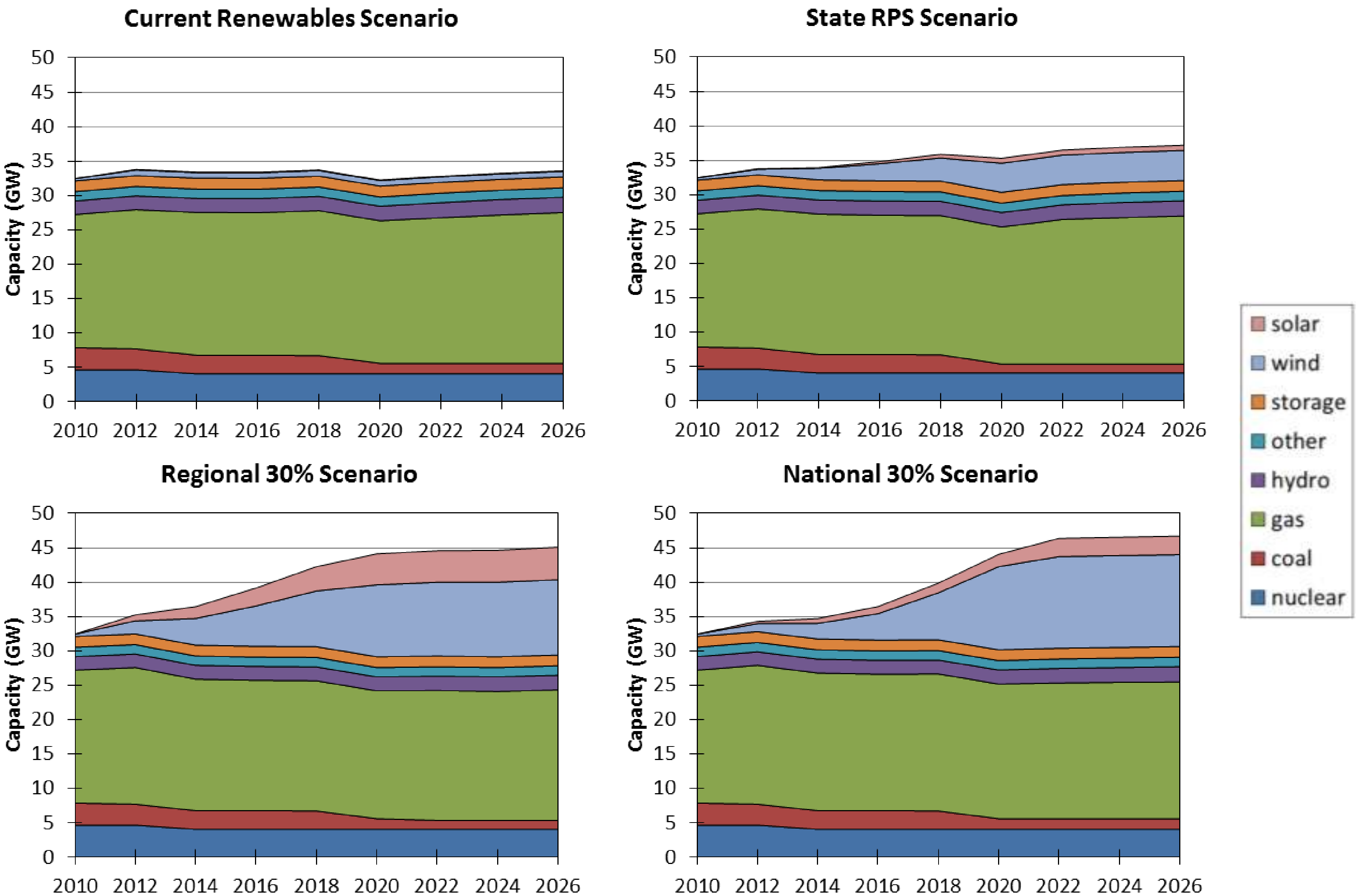
FRCC Installed Capacity by Type



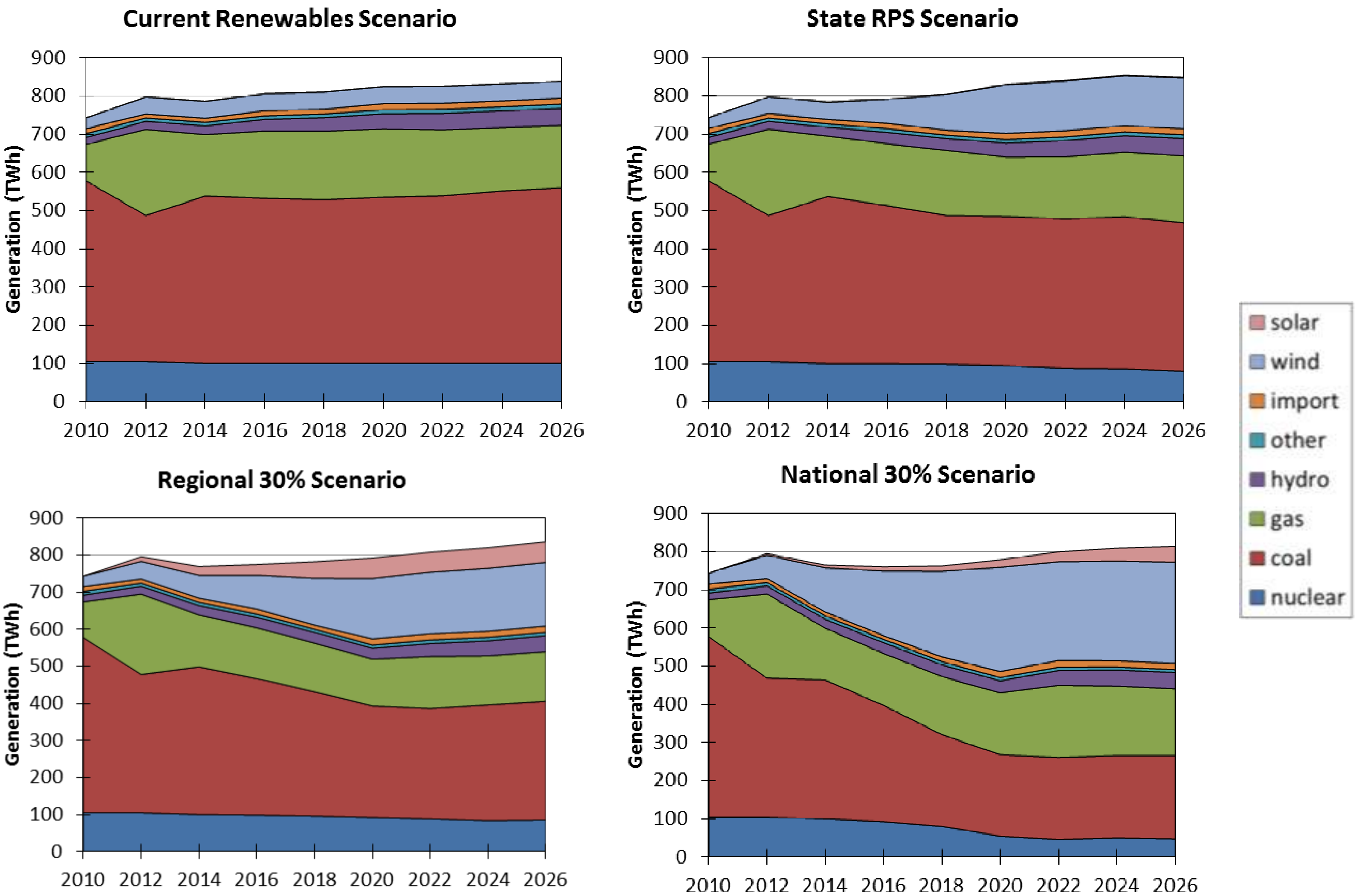
ISO-NE Generation by Type



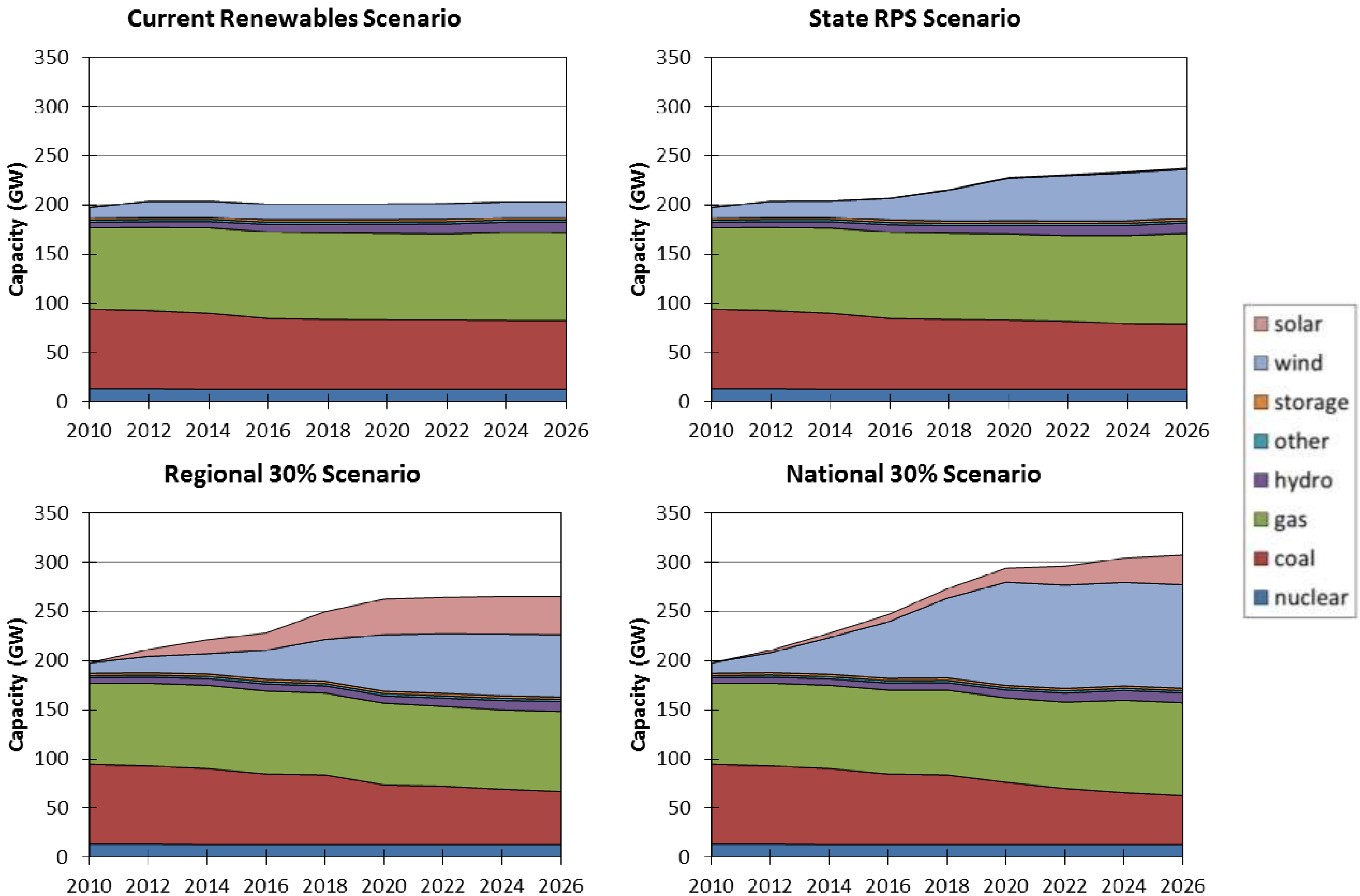
ISO-NE Installed Capacity by Type



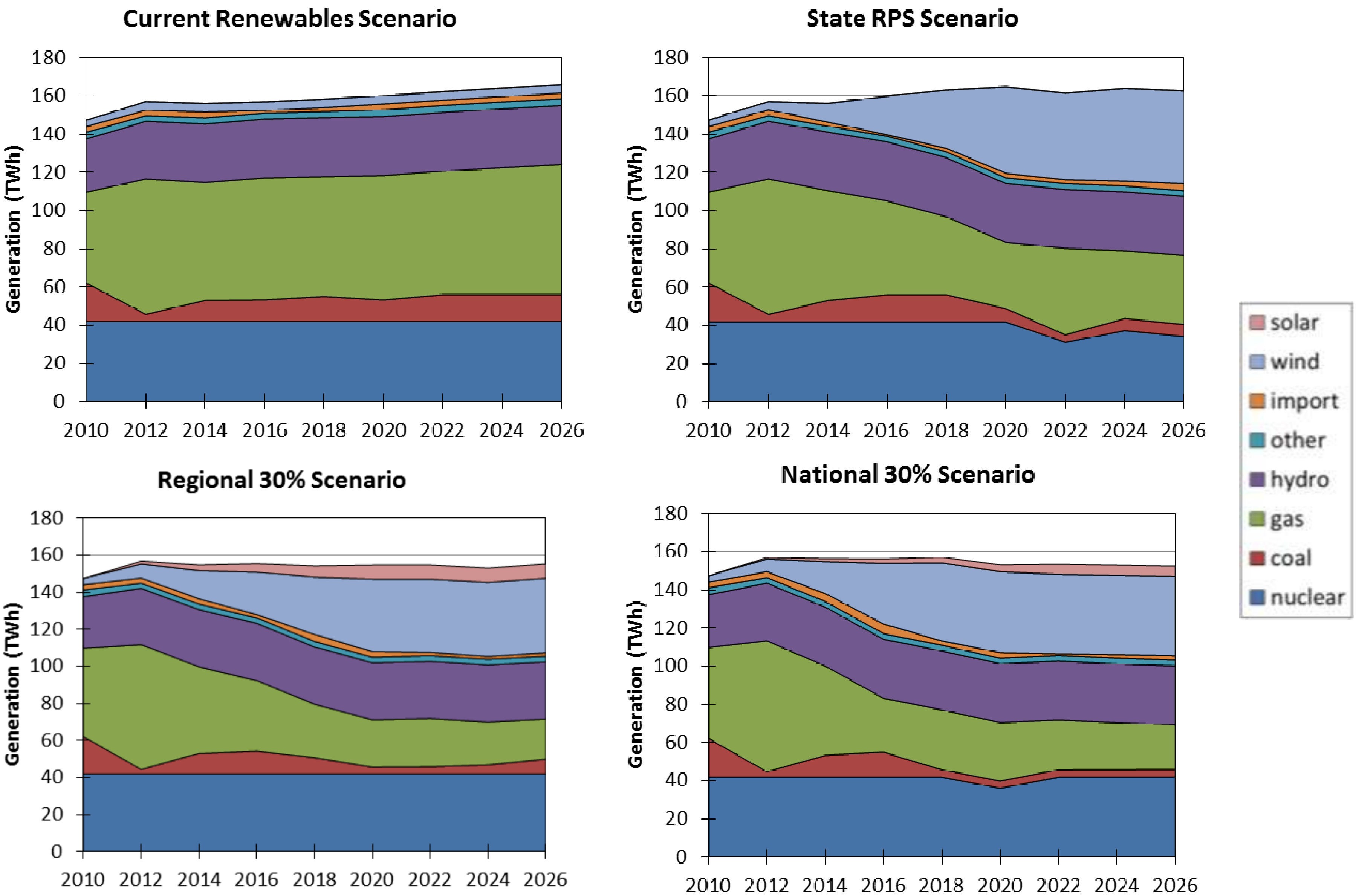
MISO Generation by Type



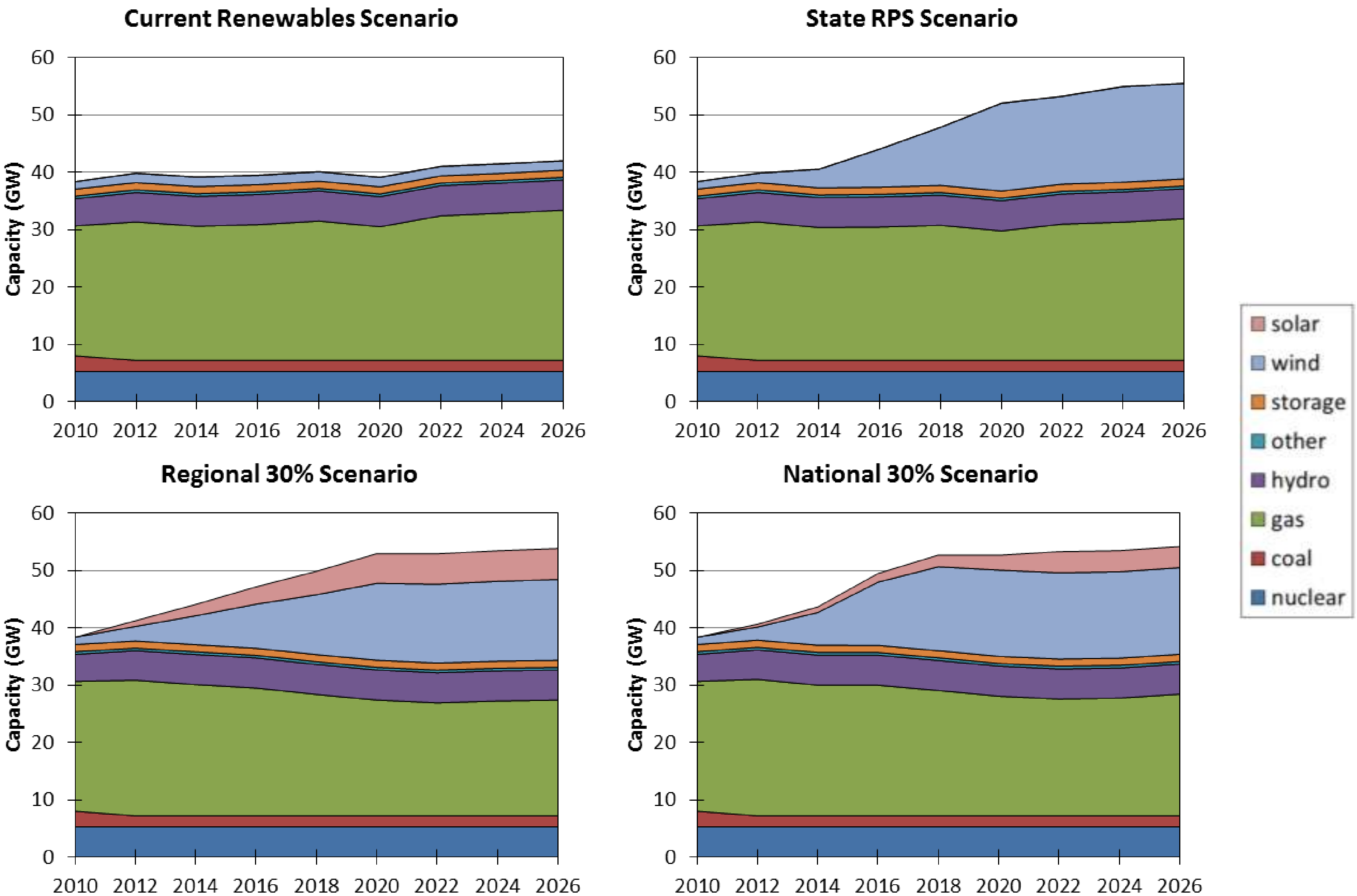
MISO Installed Capacity by Type



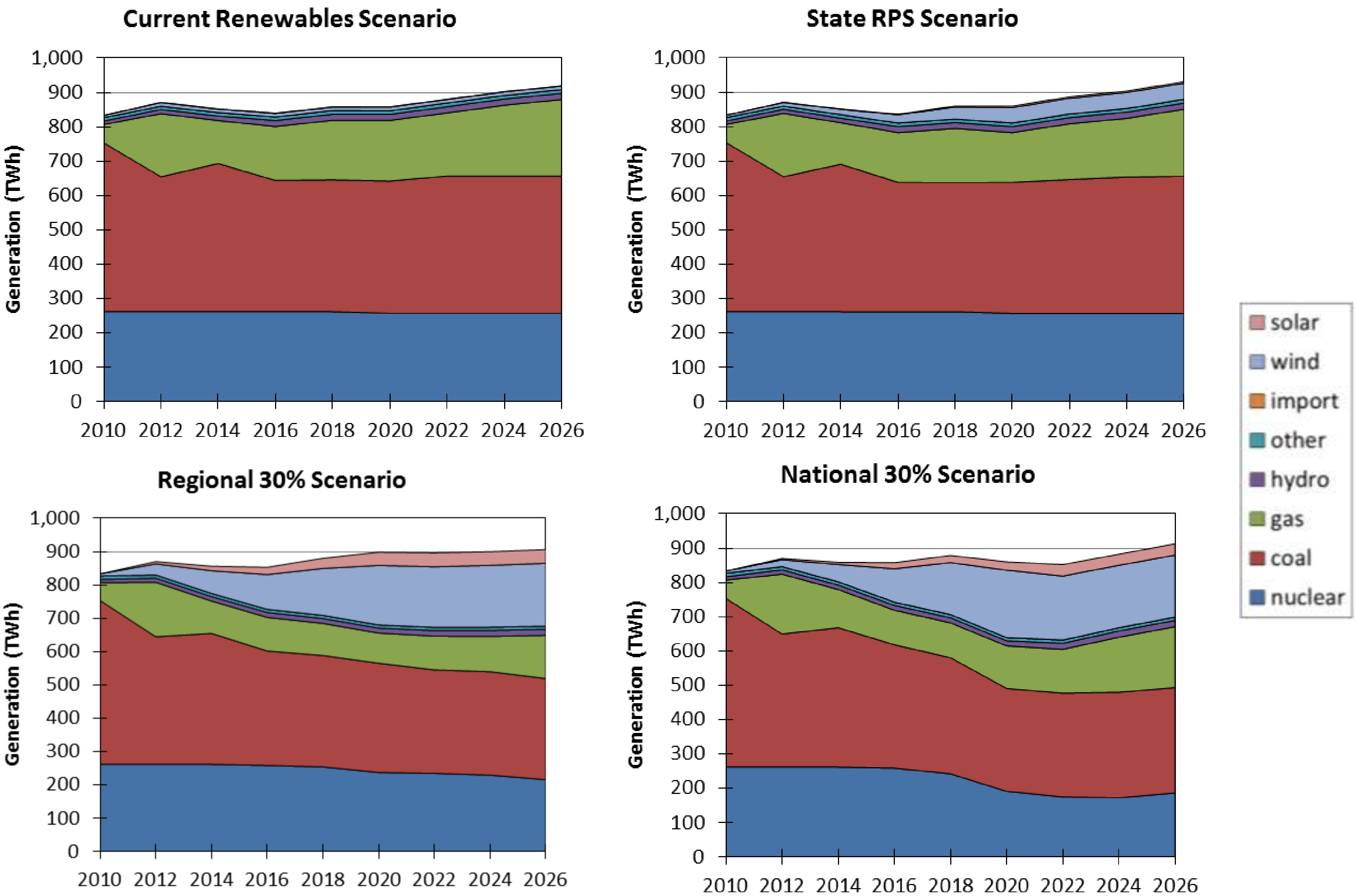
NYISO Generation by Type



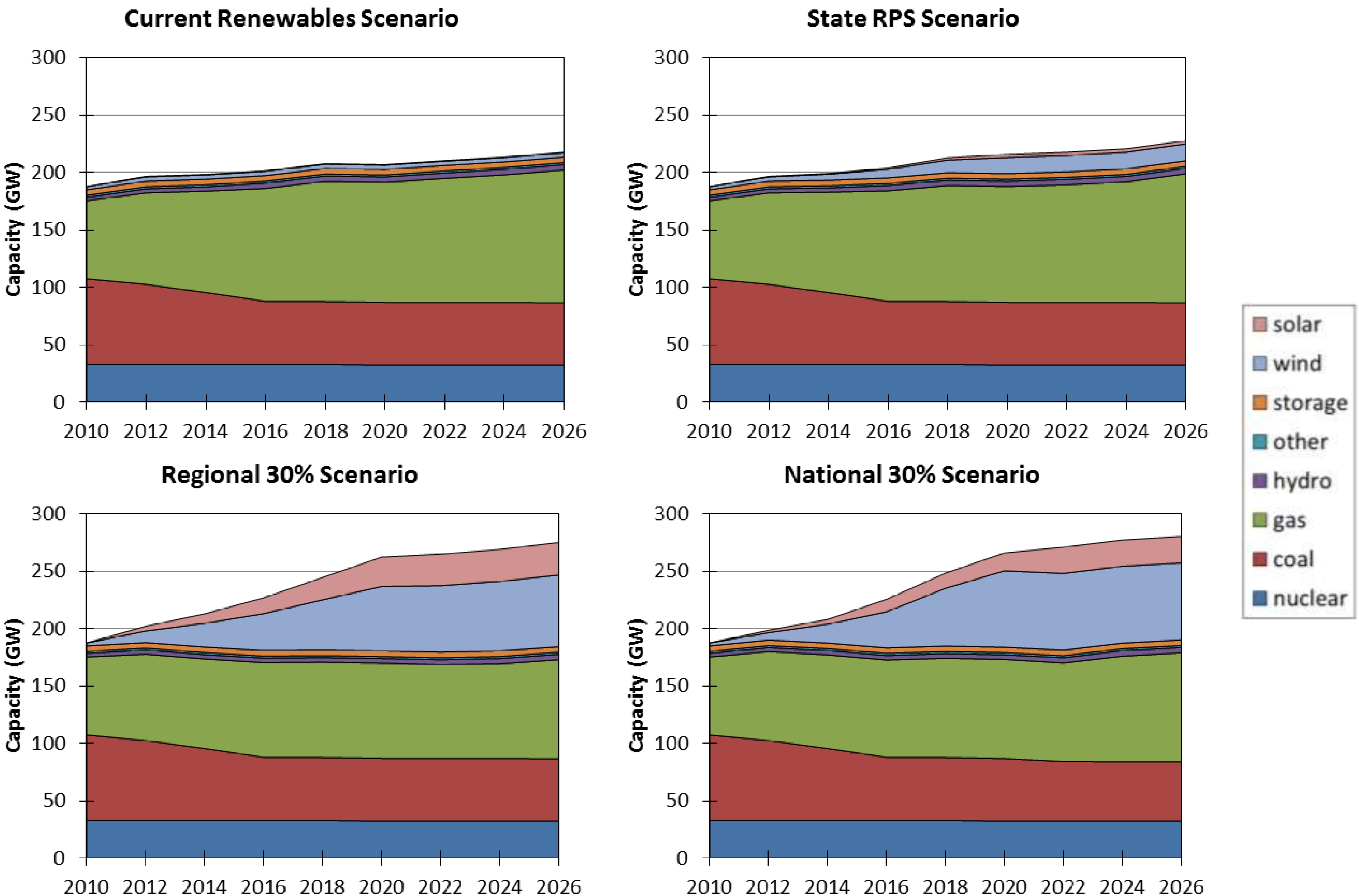
NYISO Installed Capacity by Type



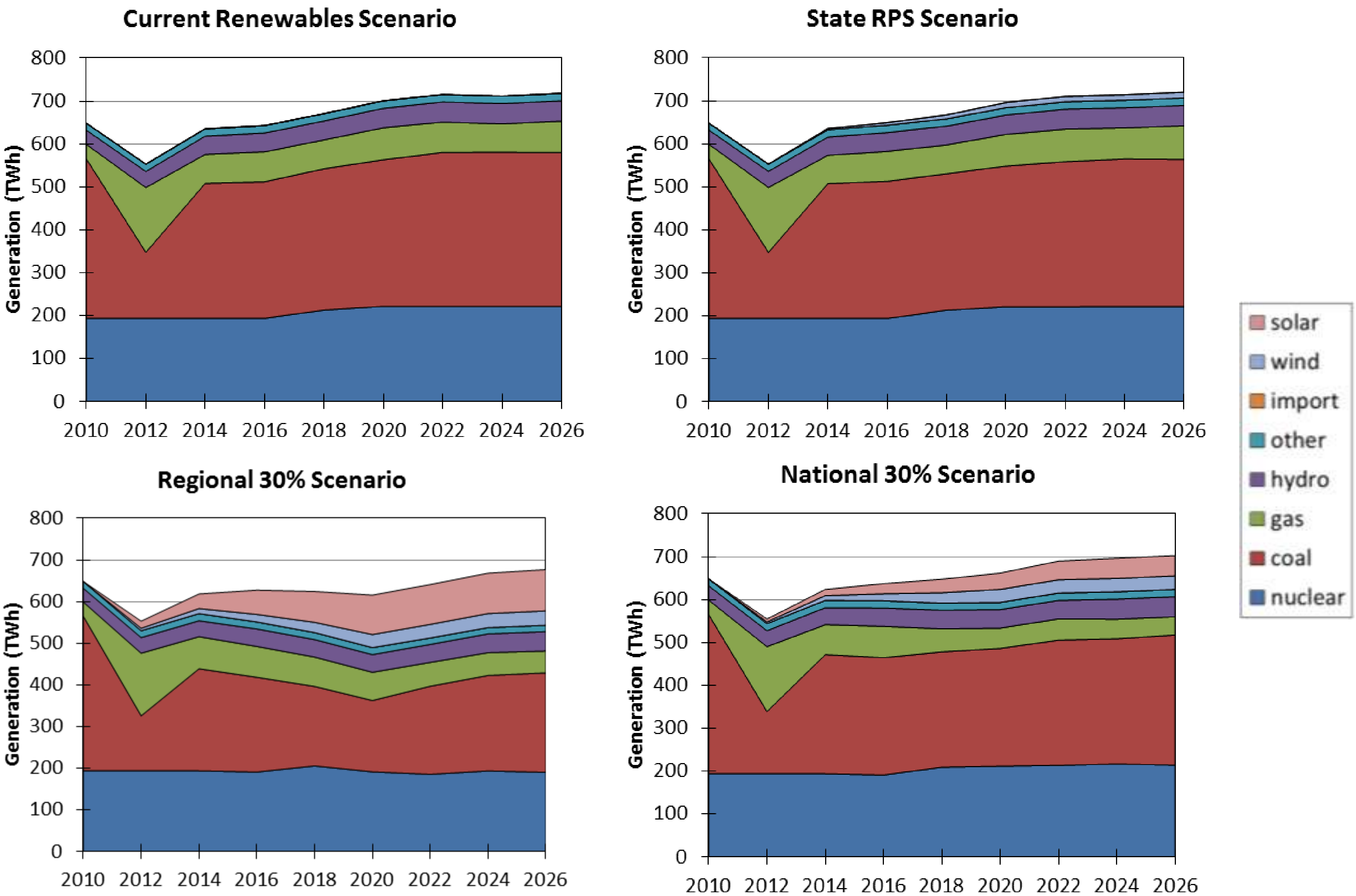
PJM Generation by Type



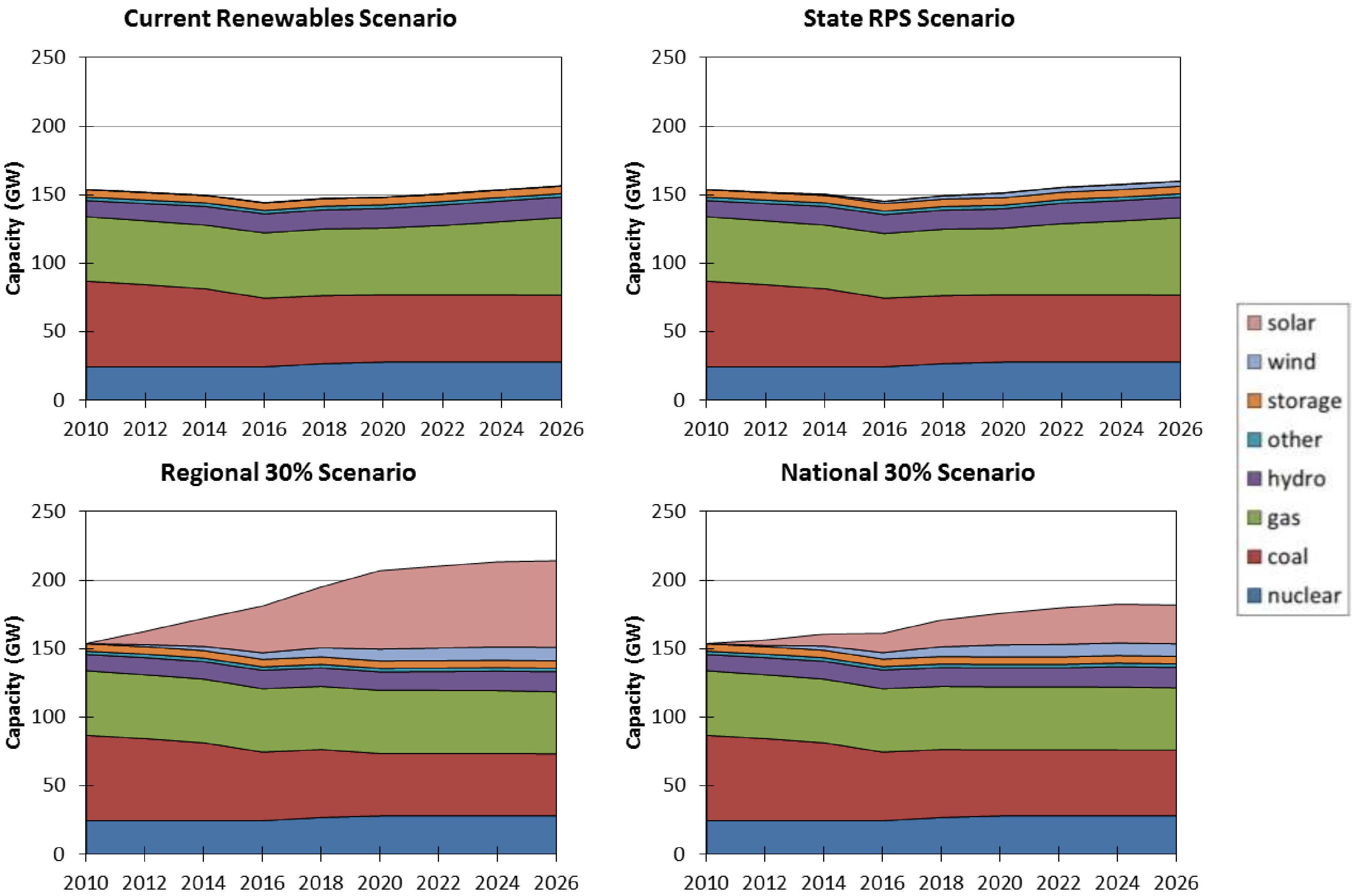
PJM Installed Capacity by Type



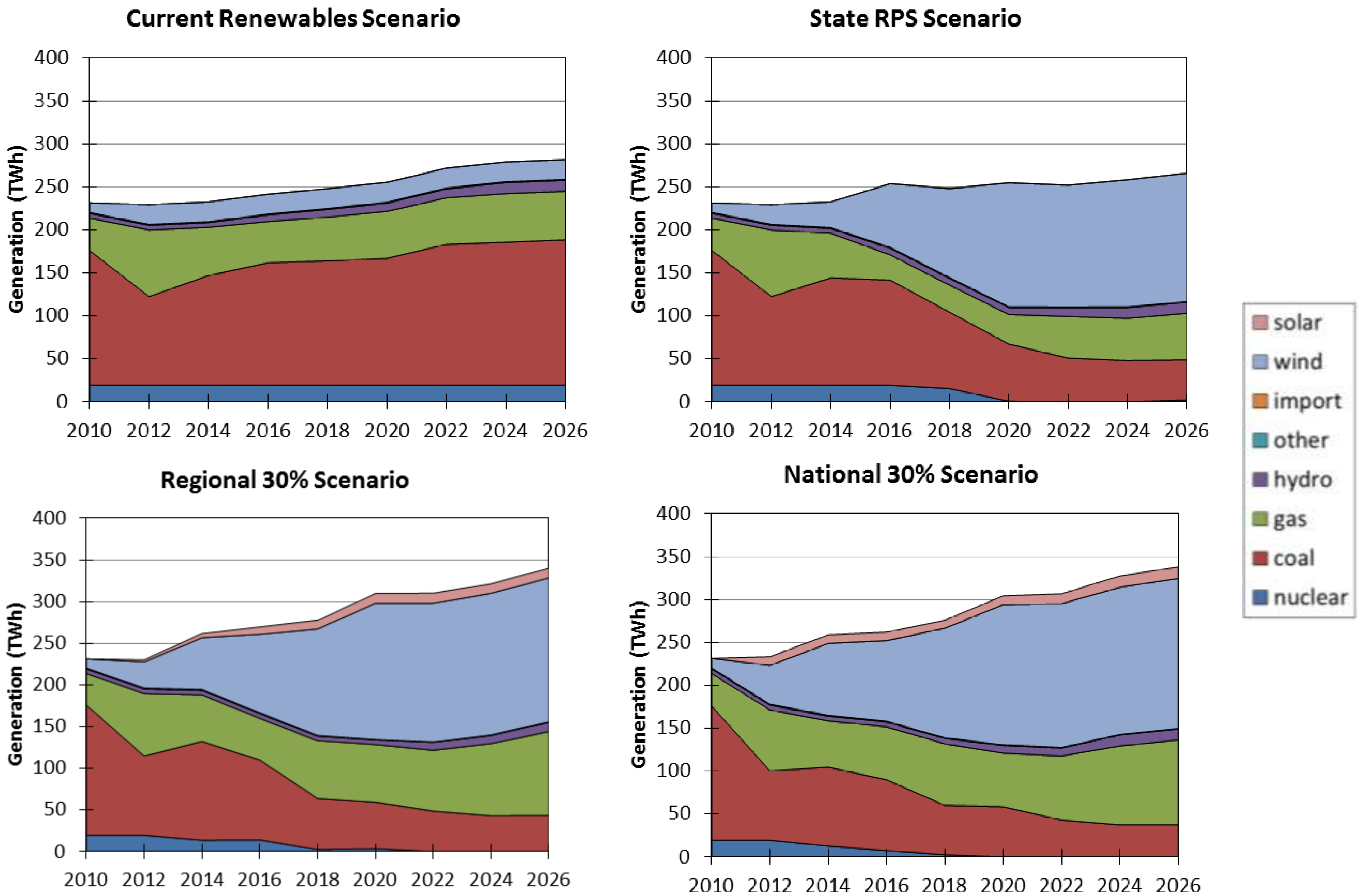
SERC Generation by Type



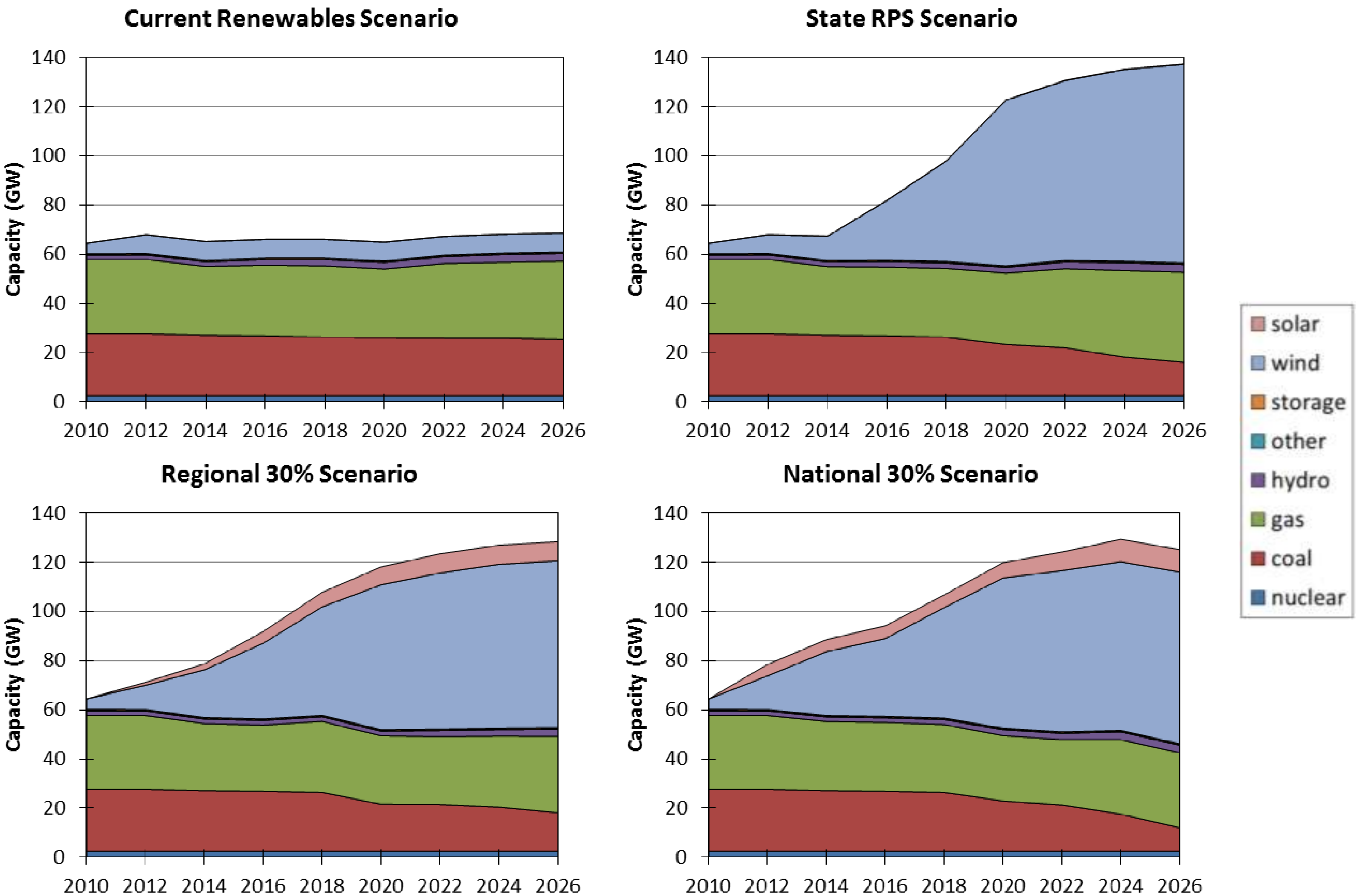
SERC Installed Capacity by Type



SPP Generation by Type



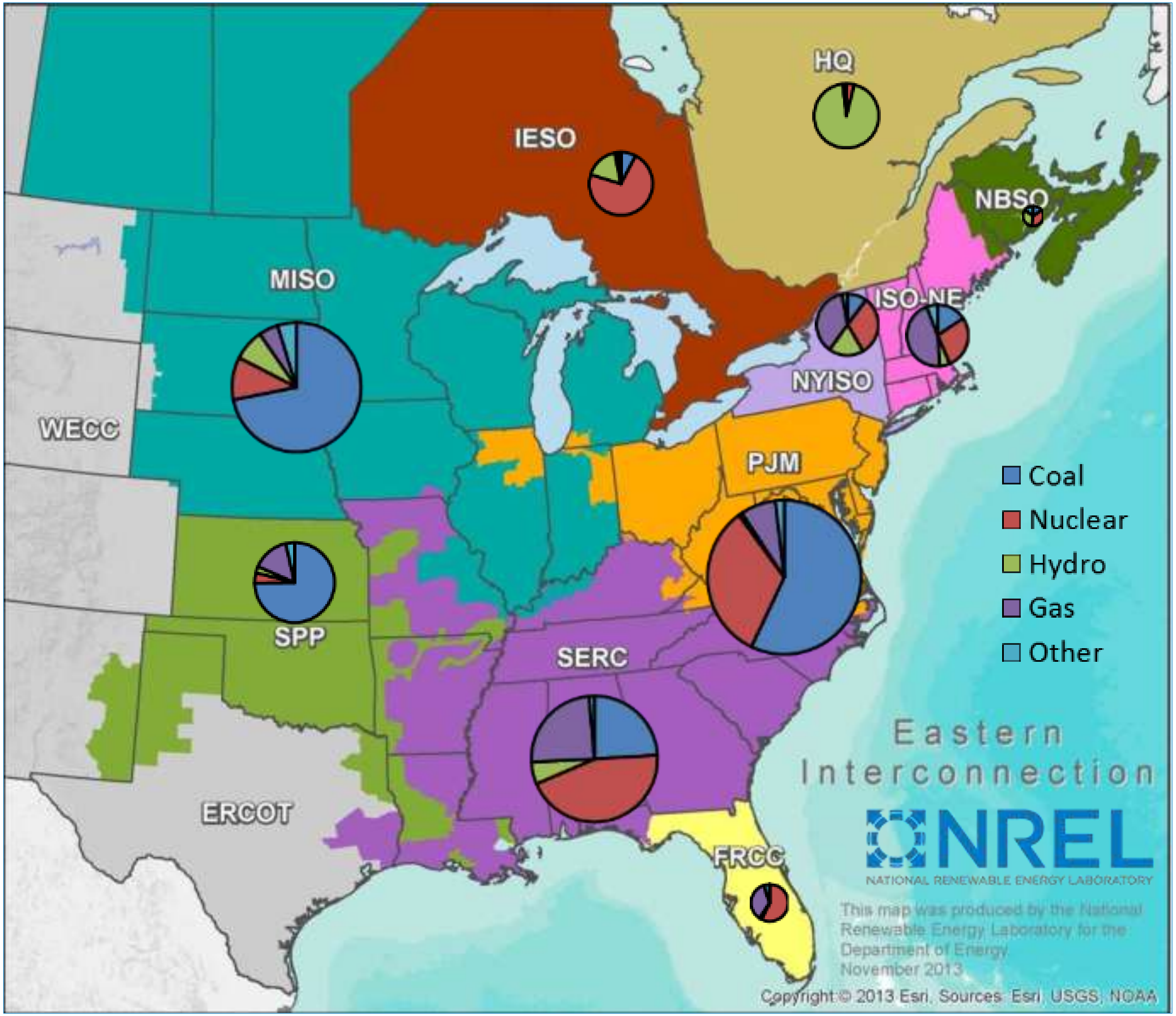
SPP Installed Capacity by Type



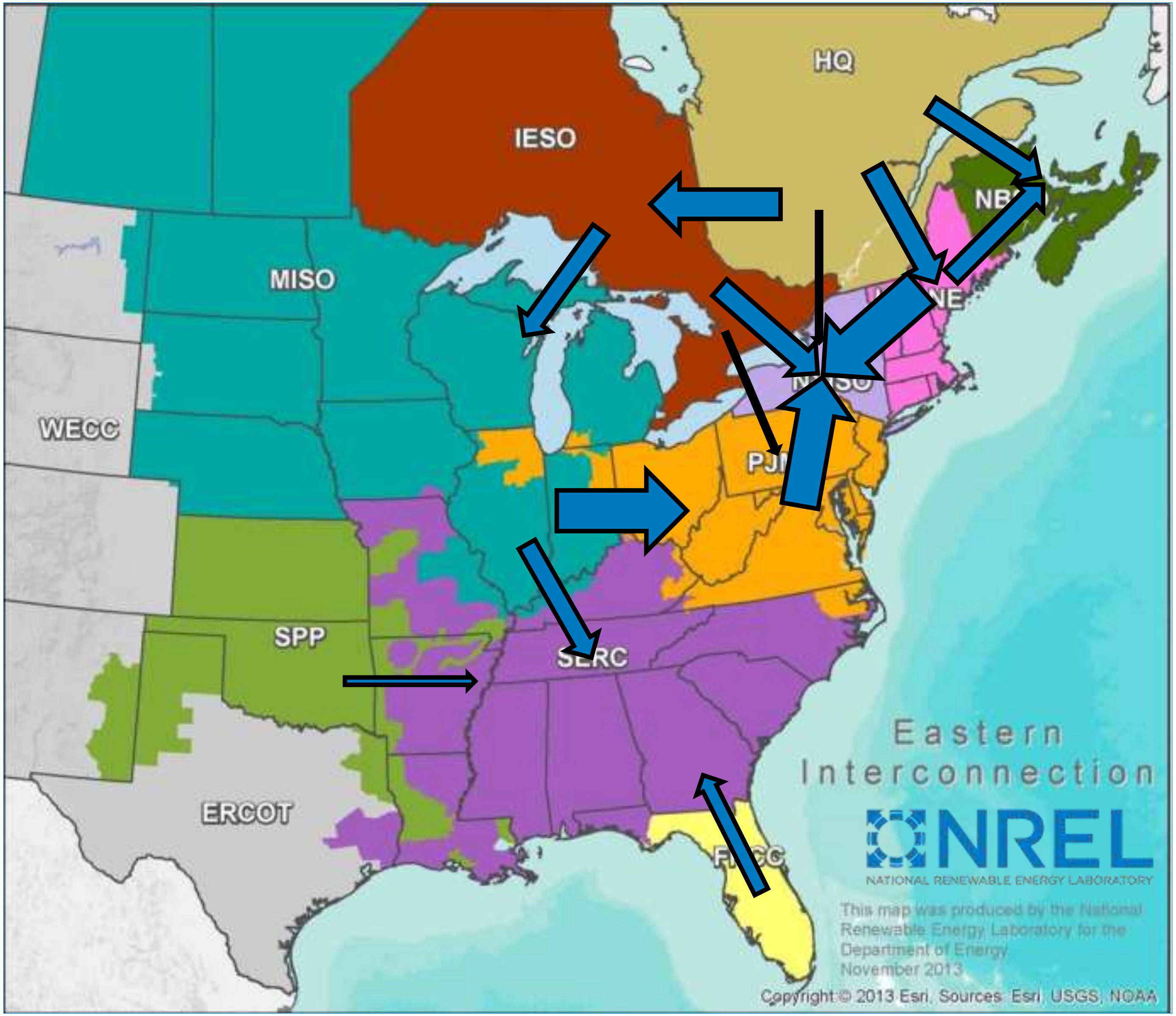
Lunch: 30 Minutes

Benchmarking

Original 2010 Run Results: Generation by Region



Original 2010 Run Results: Net Interchange Flows

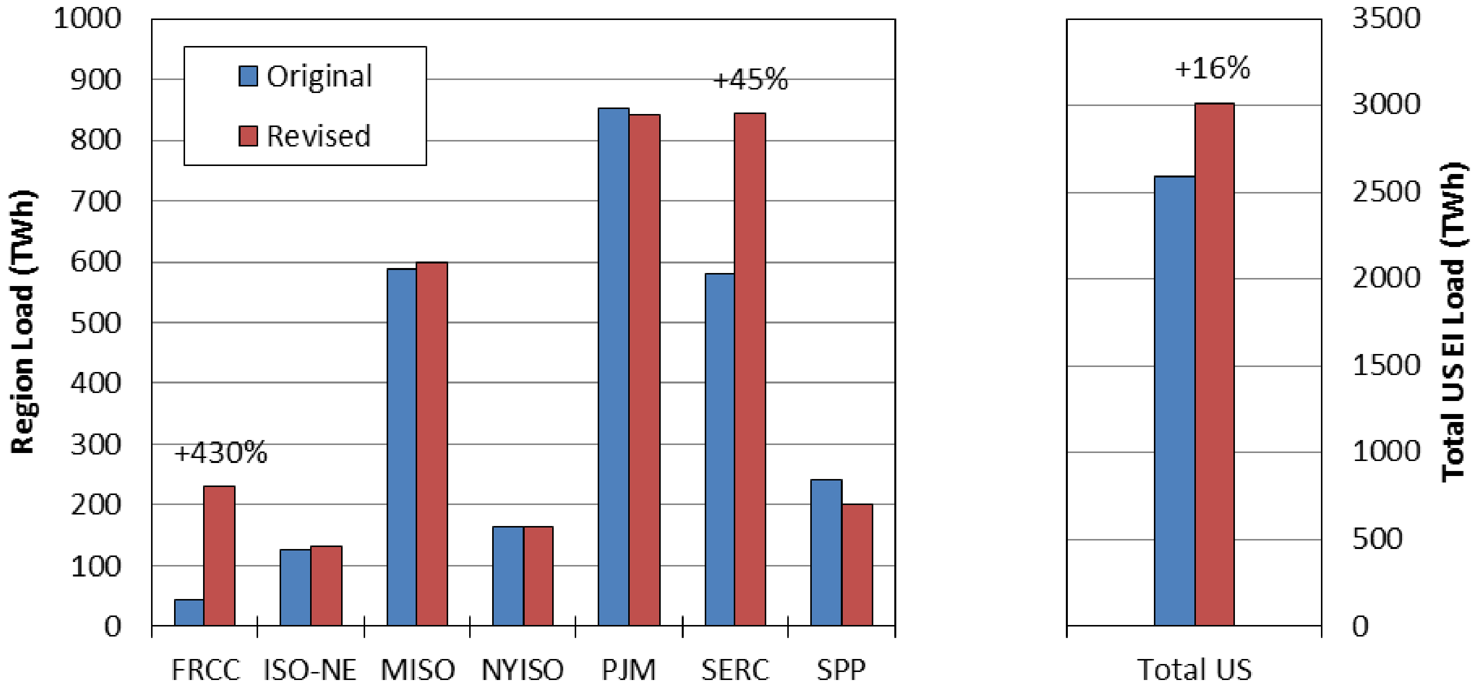


2010 Benchmarking Exercises

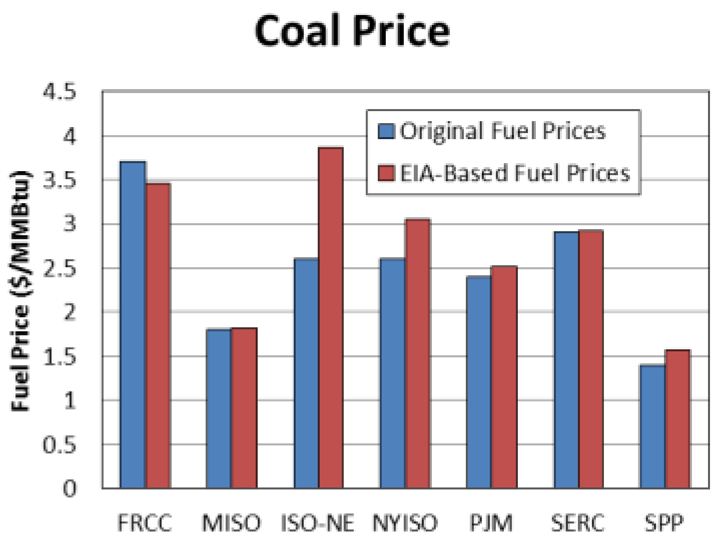
- Load
- Fuel prices
- Transmission zones
- Reference information (EIA, market reports)
- Generation by region
- Net interchange between regions

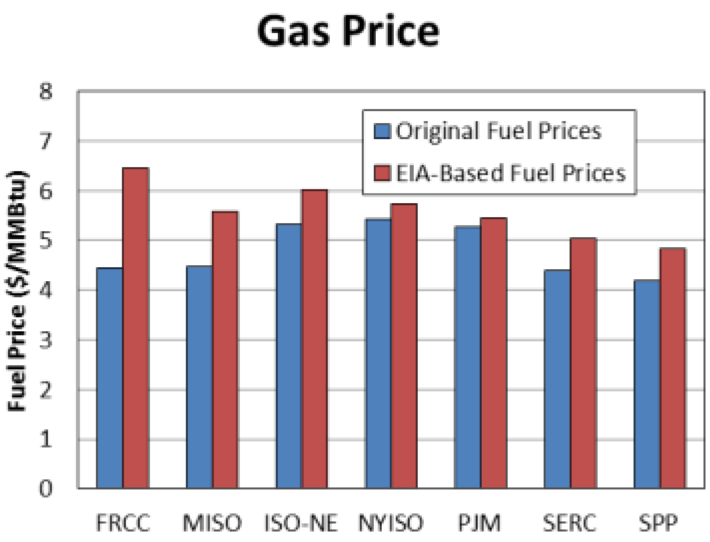
2010 Load

- **Problems with original 2010 load**
- **New 2010 load based on Ventyx data for each new region**

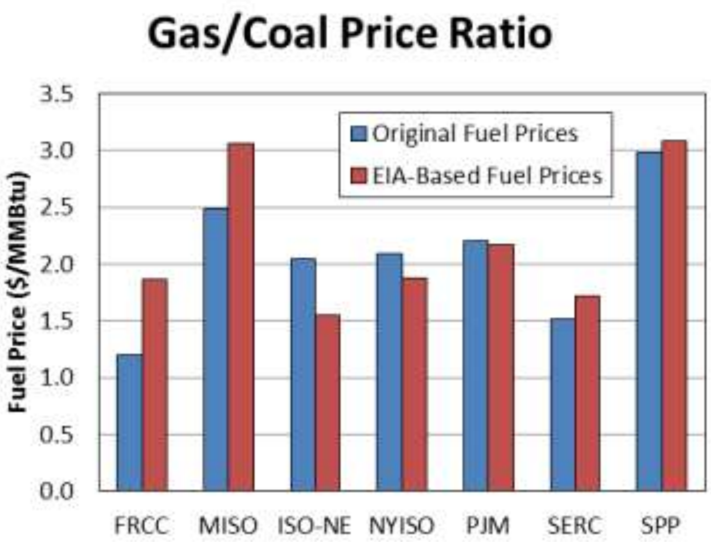


Fuel Prices



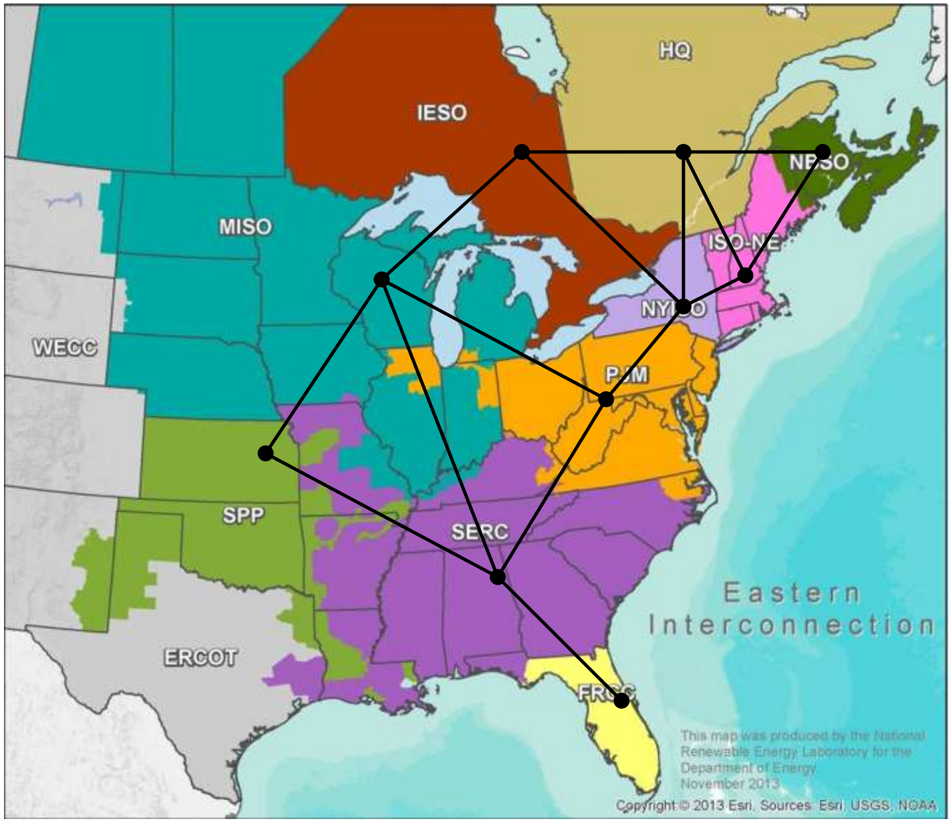


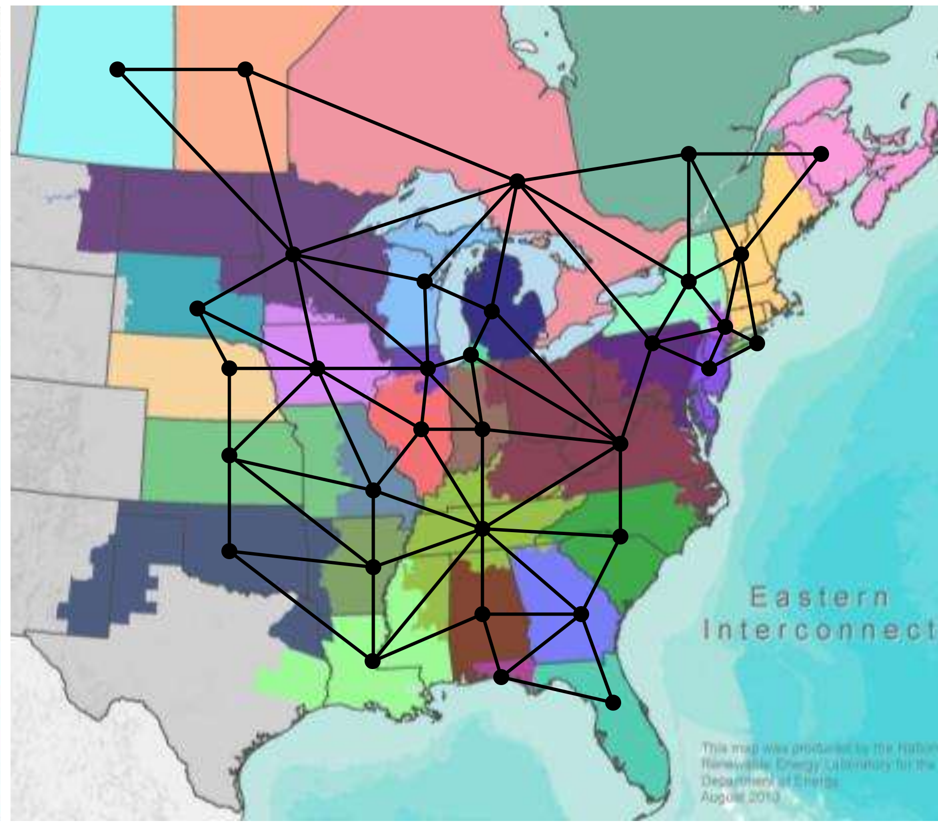
- **Revised to EIA-based values**
- **Gas/coal price ratios changed due to revision**



Transmission Zones

- **Regions sub-divided to provide greater resolution of transmission constraints (10 nodes increased to 35 nodes)**

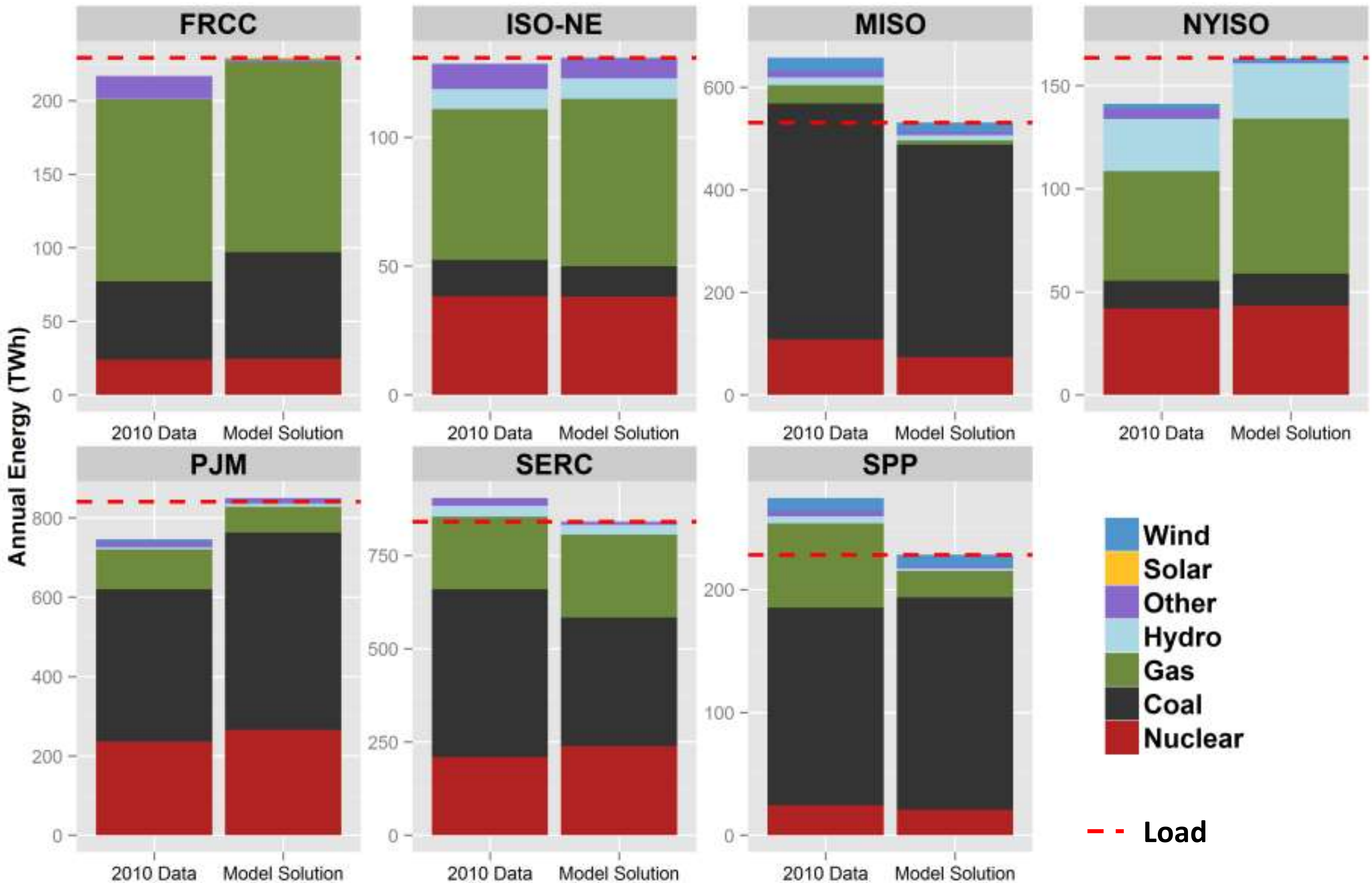




2010 Run Details

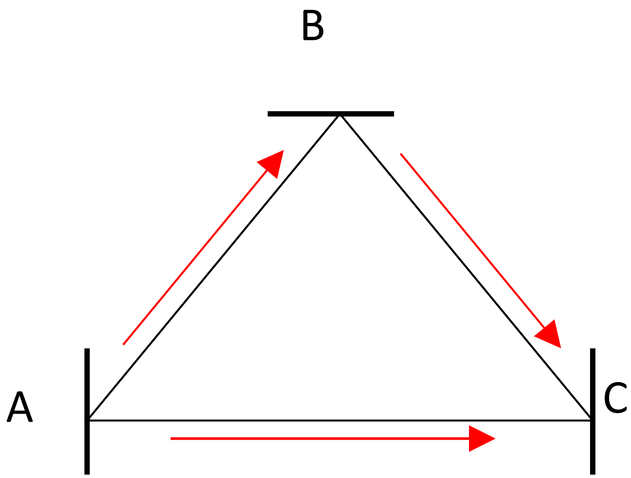
- **Day-ahead only**
- **33 Eastern Interconnection sub-regions**
- **Neglect interactions with ERCOT and WECC**
- **Single reserve product each EI region**
  - 2.5% of region load
  - 10 minute response time

Isolated Regions: Generation by Region



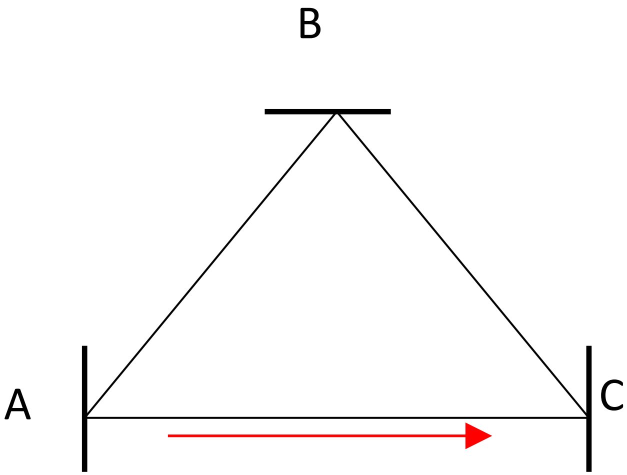
2010 Run Details: With Transmission

DC Power Flow



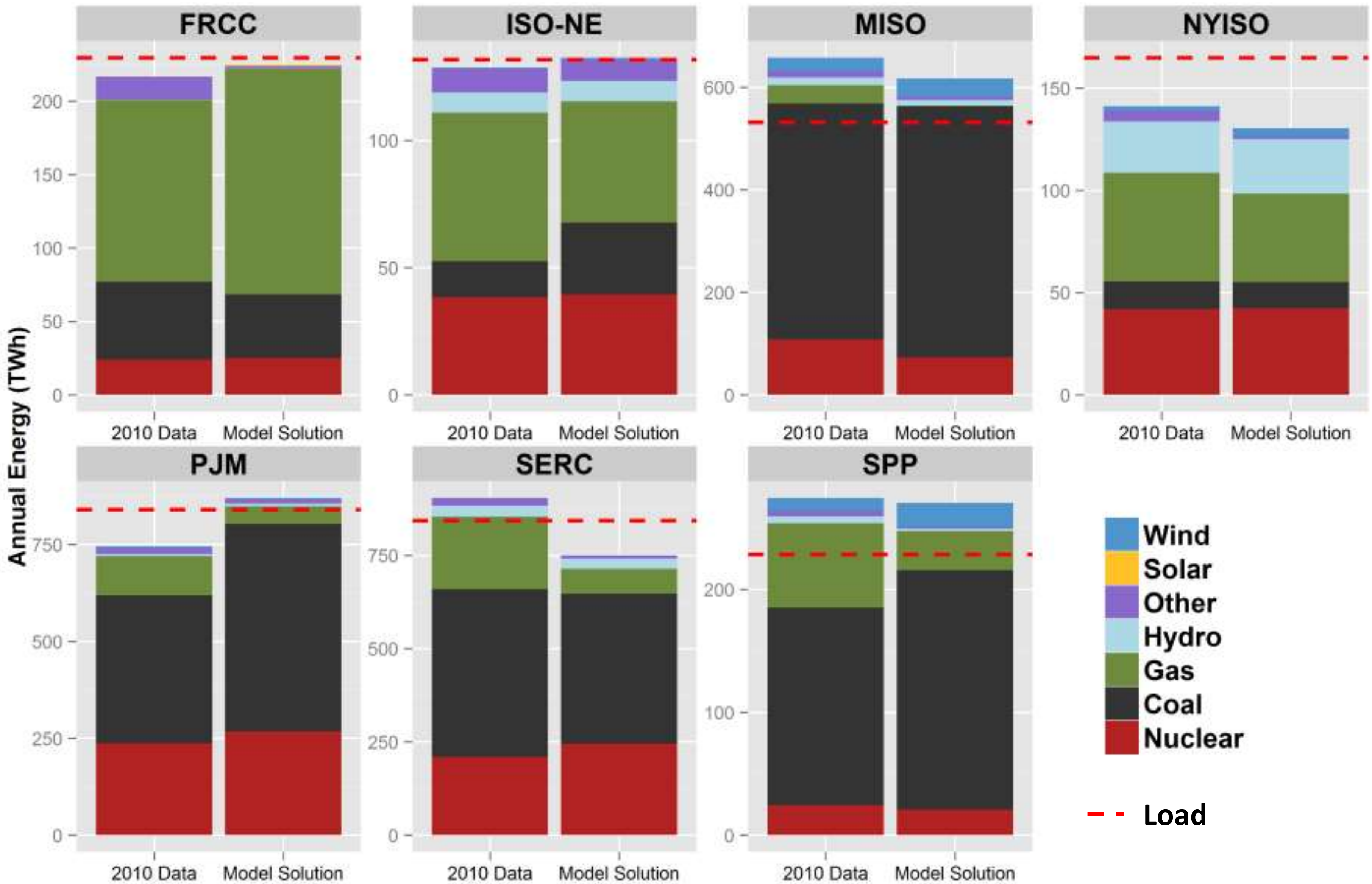
- $0 hurdle rates between regions

Transport Model



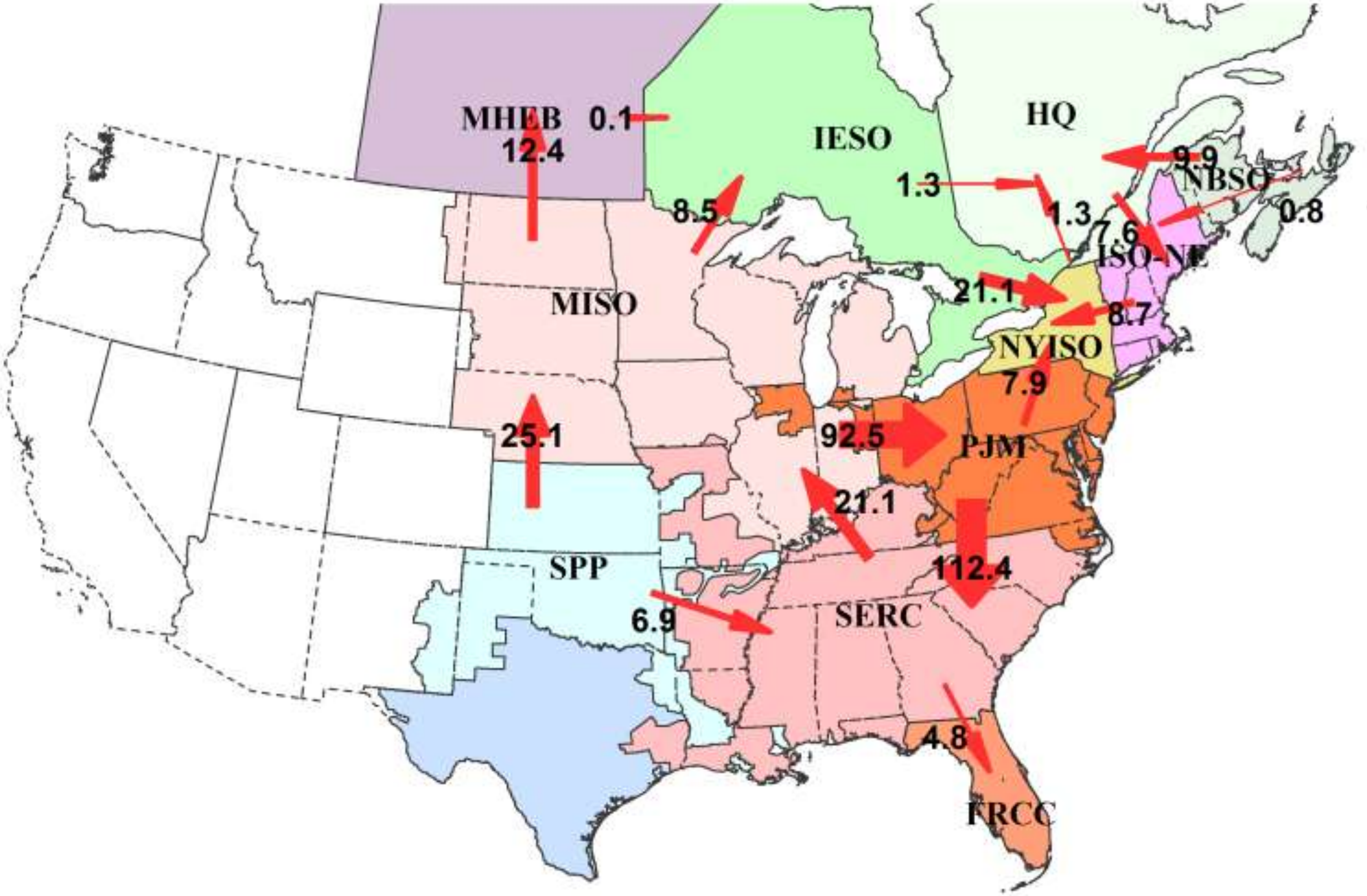
- $0 and $10 hurdle rates between regions

DC Power Flow

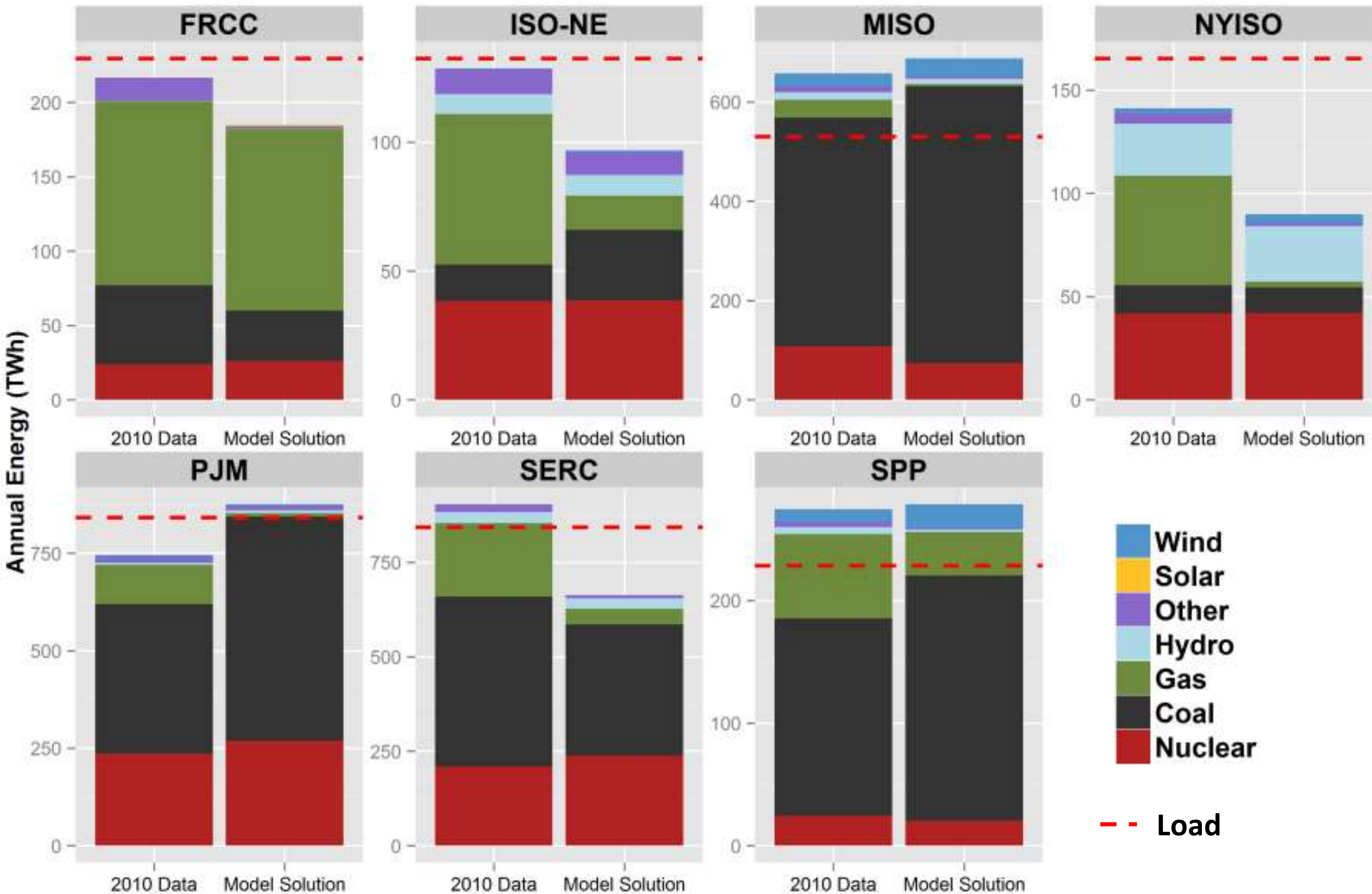


DC Power Flow

Net Transfers Between Regions (TWh)

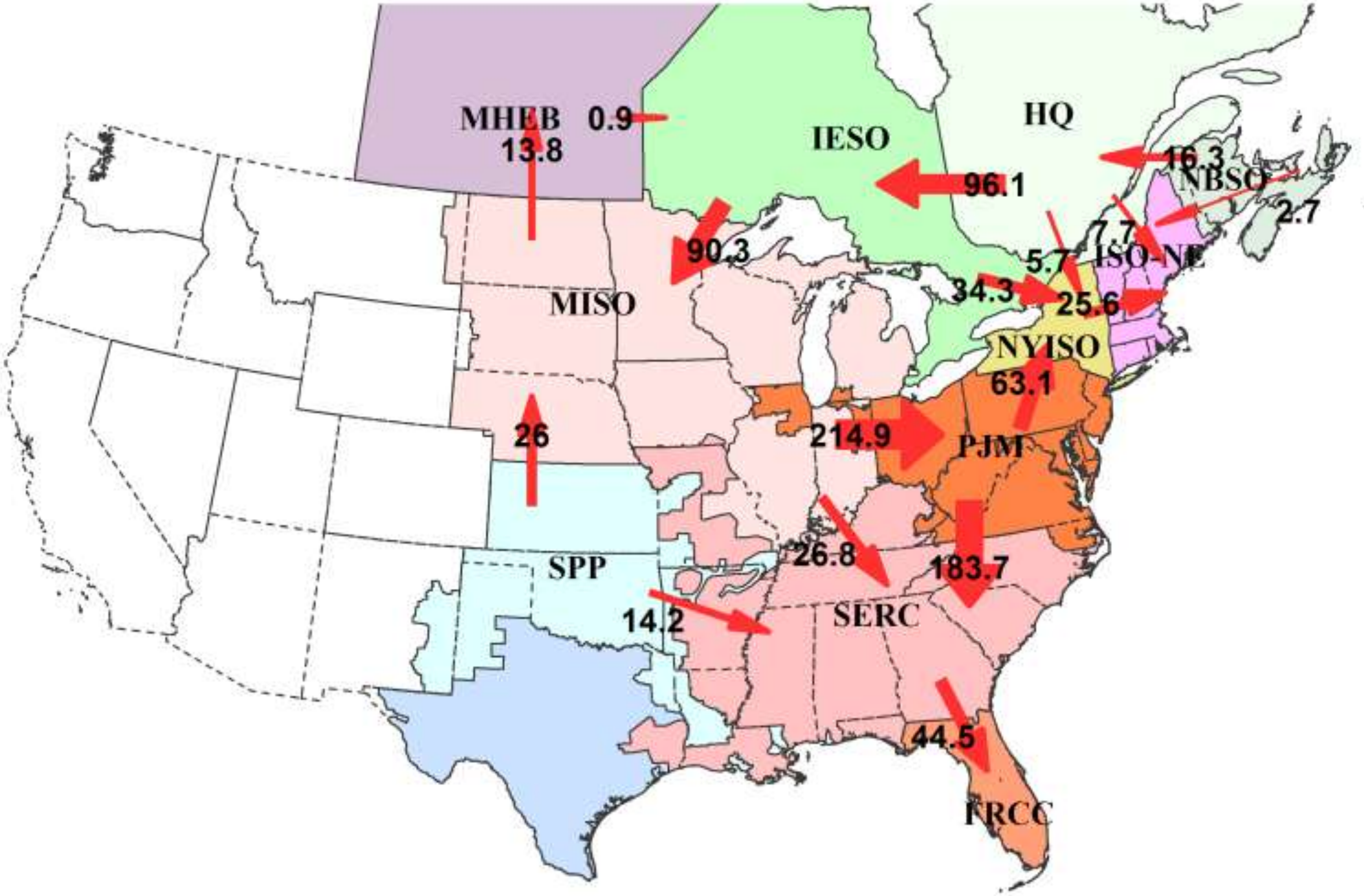


Transport Model without Hurdle Rates

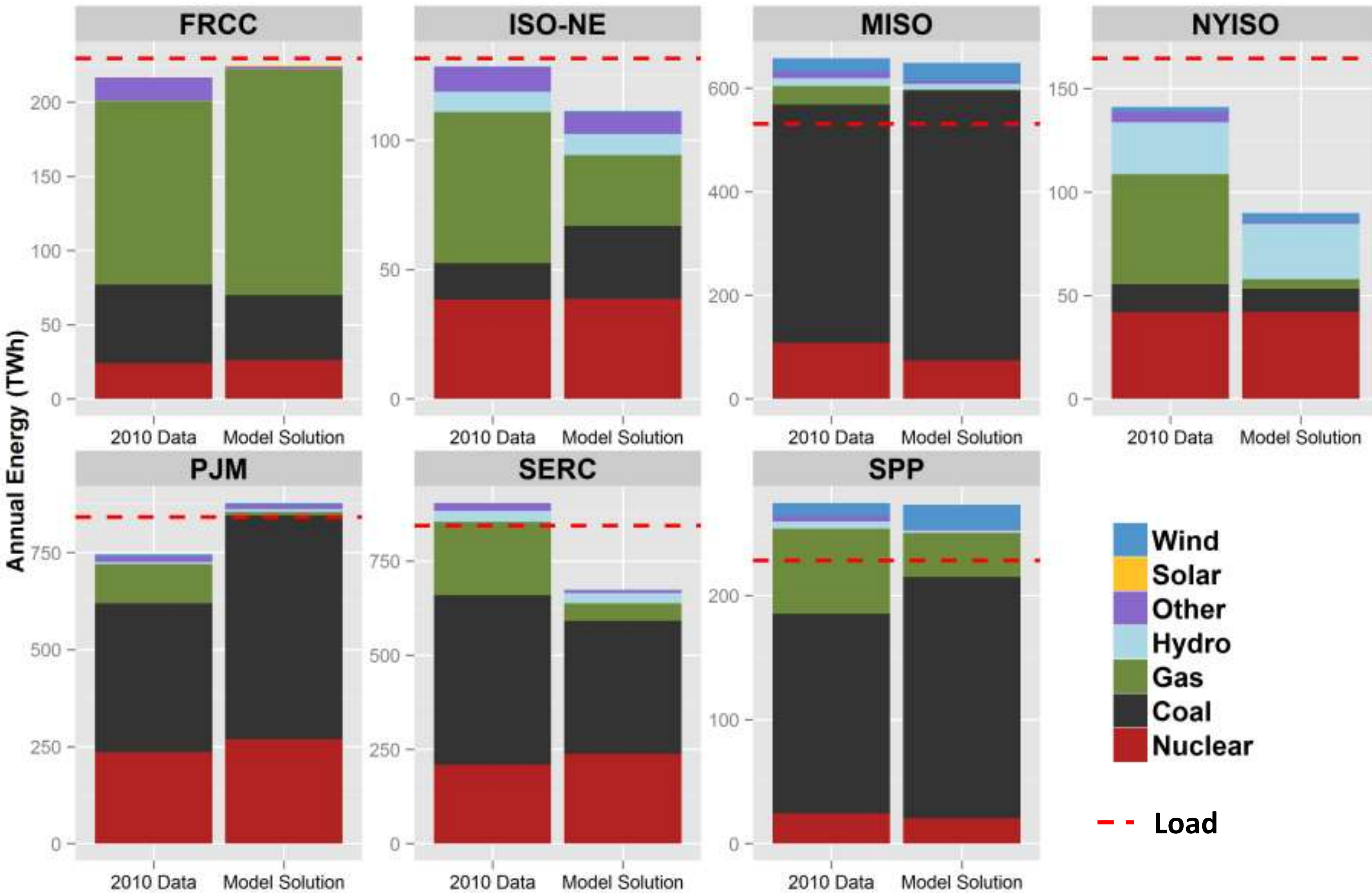


Transport Model without Hurdle Rates

Net Transfers Between Regions (TWh)

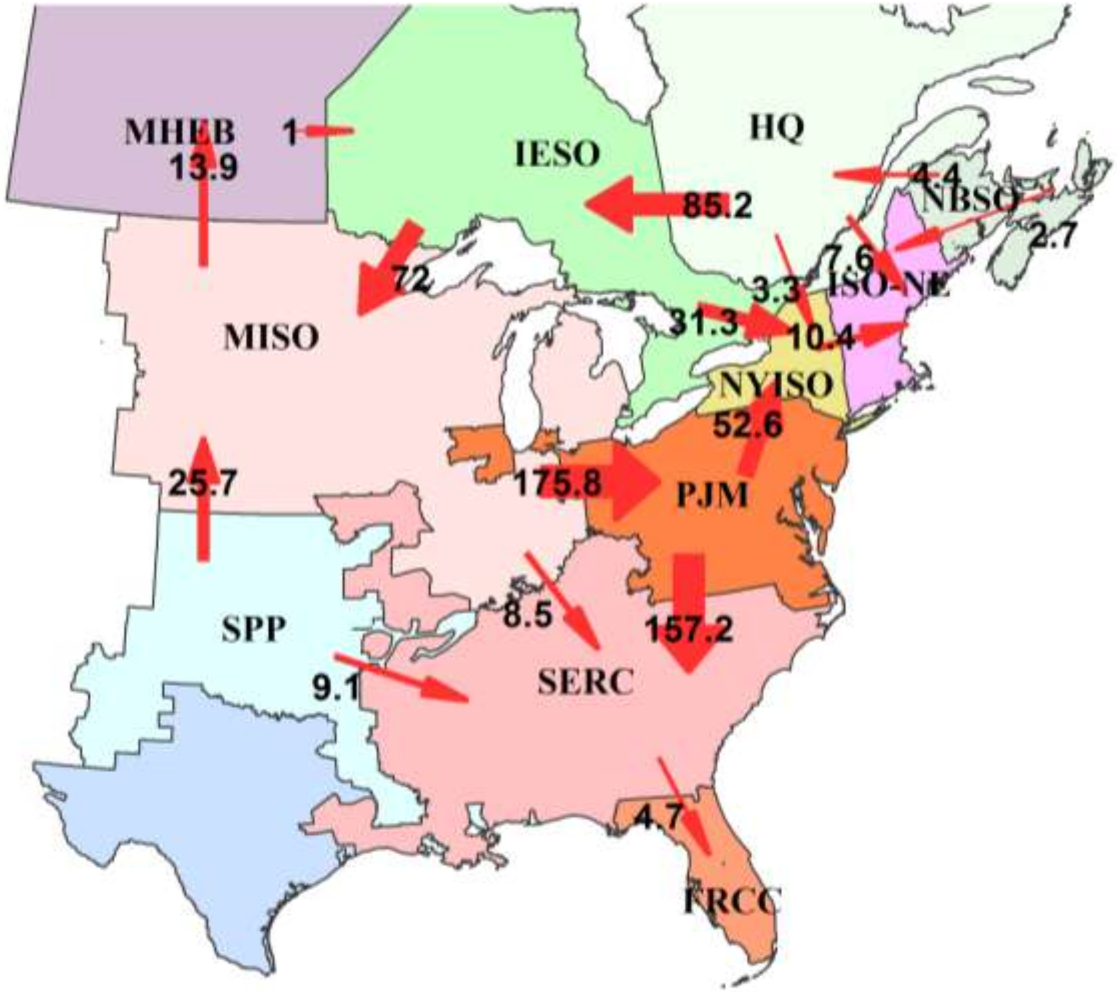


Transport Model with $10 Hurdle Rates



Transport Model with $10 Hurdle Rates

Net Transfers Between Regions (TWh)

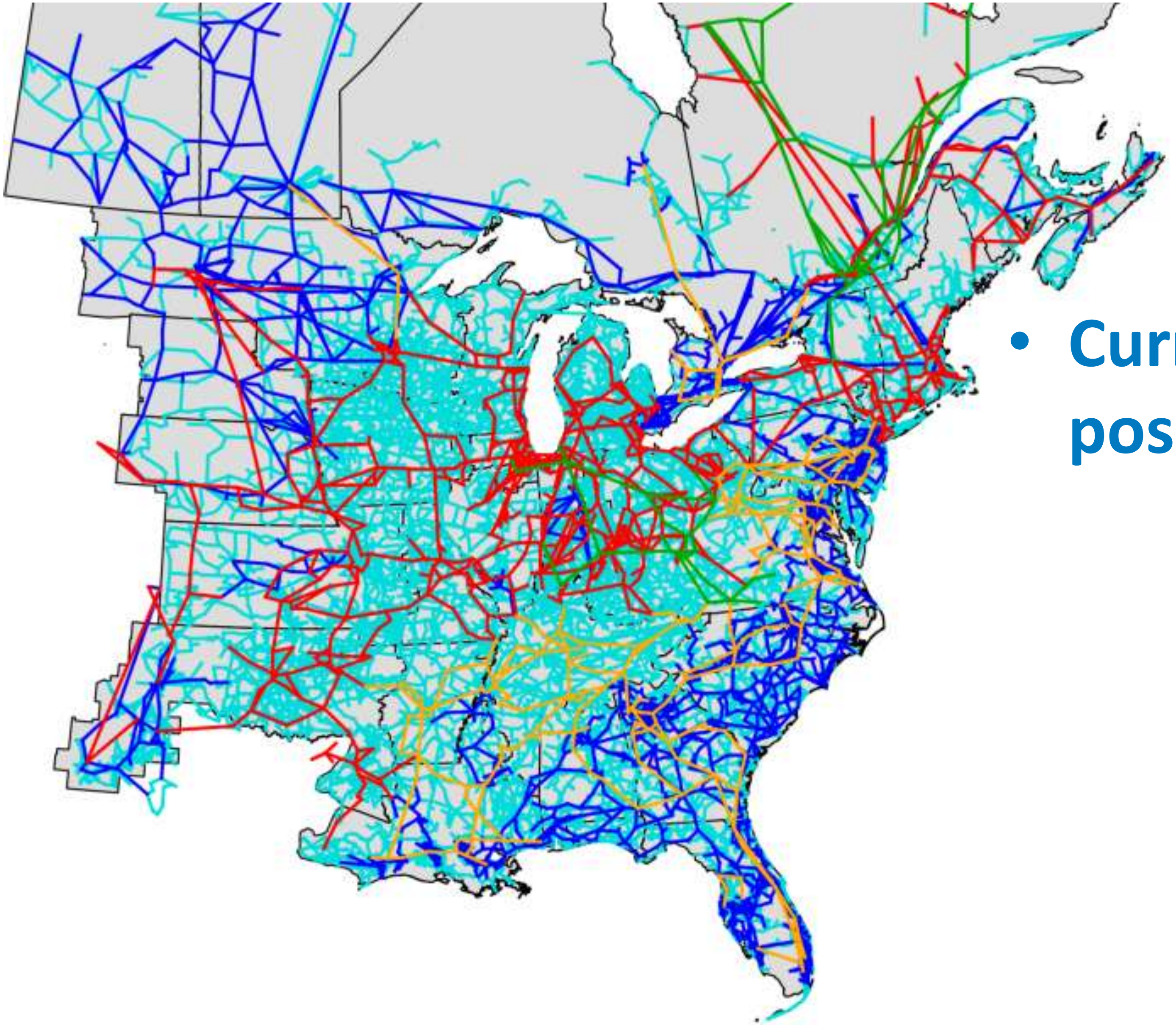


Transmission Representation

Transmission

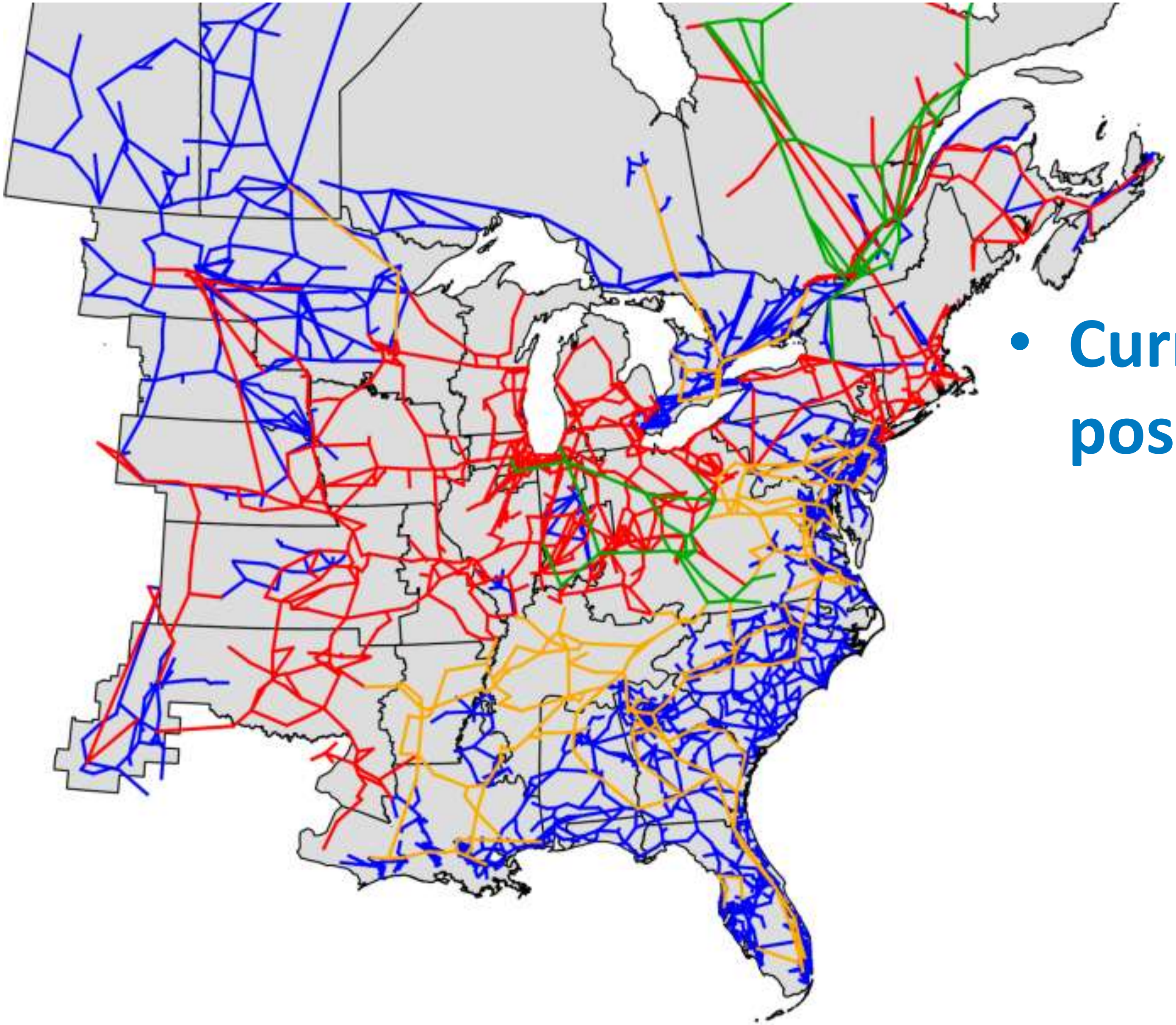
- Unreasonable runtimes running even part of full nodal
- Simplify to reduced network
- DC power flow or transport model
- Current reduced network too simple
- Appropriate number of lines and nodes?
- Appropriate equivalencing method?
- Effect on runtime compared to existing approach?

Full Network: All Transmission Lines



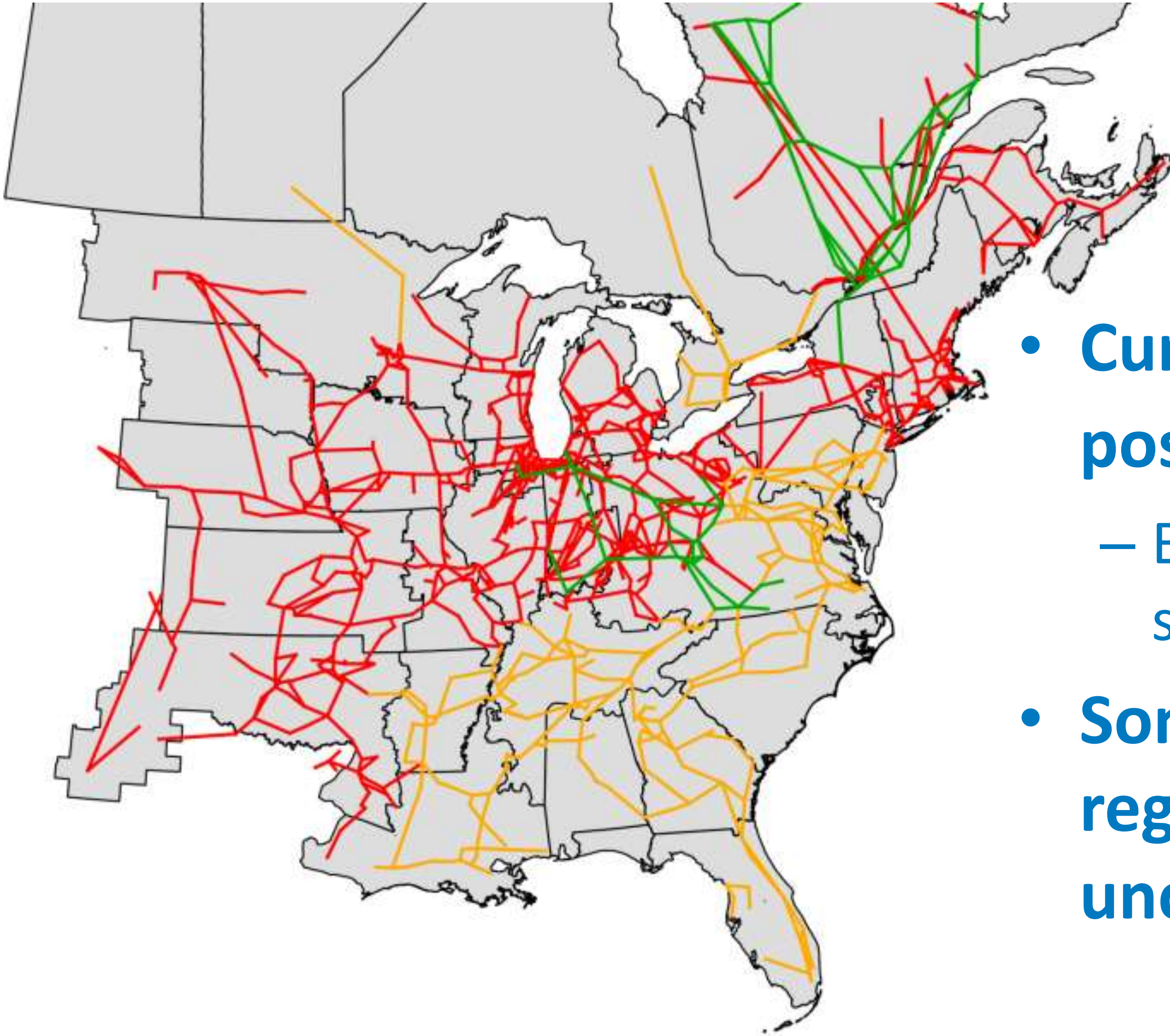
- **Currently not possible**

Network Simplification: Lines >200 kV



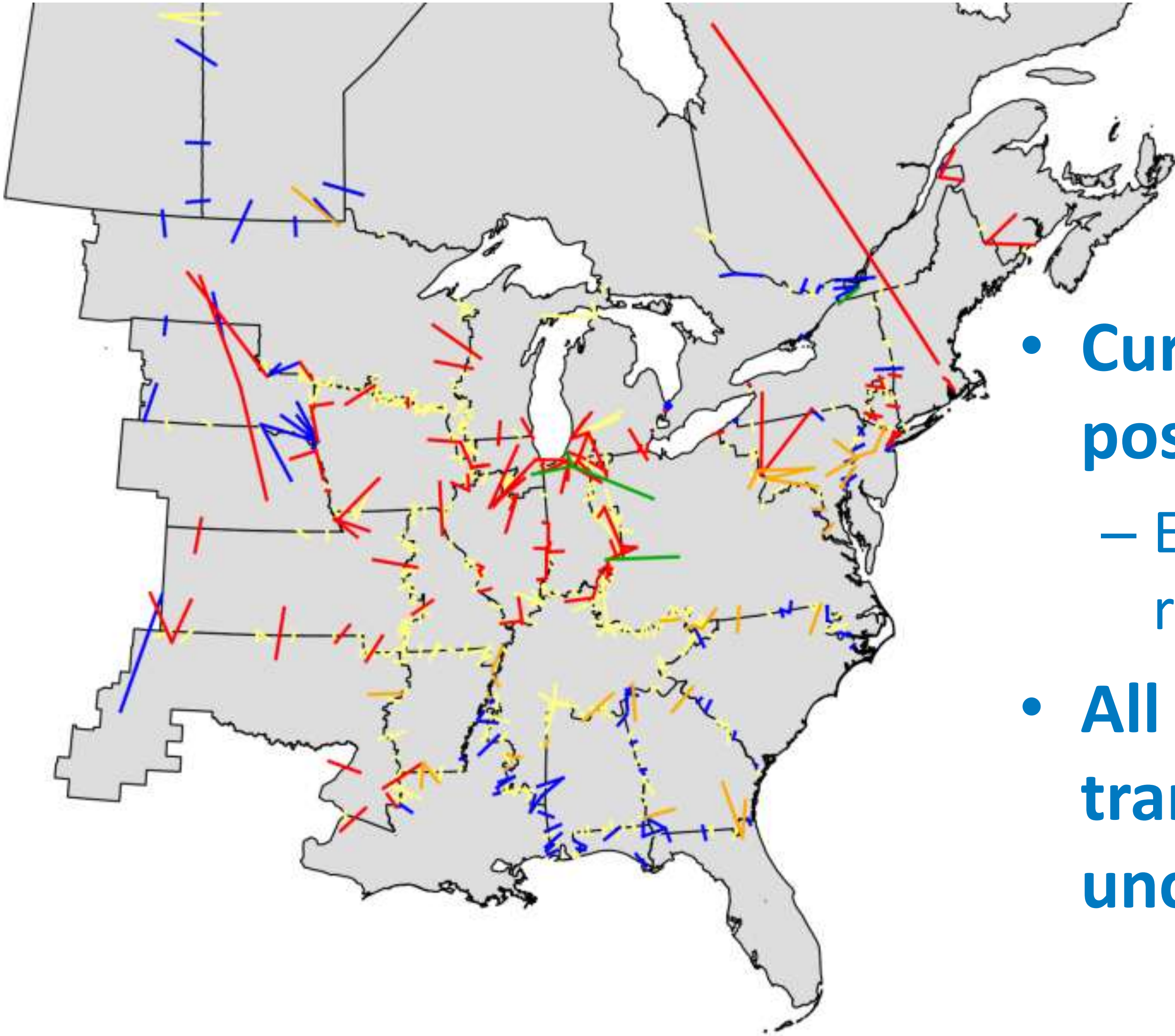
- **Currently not possible**

Network Simplification: Lines >300 kV



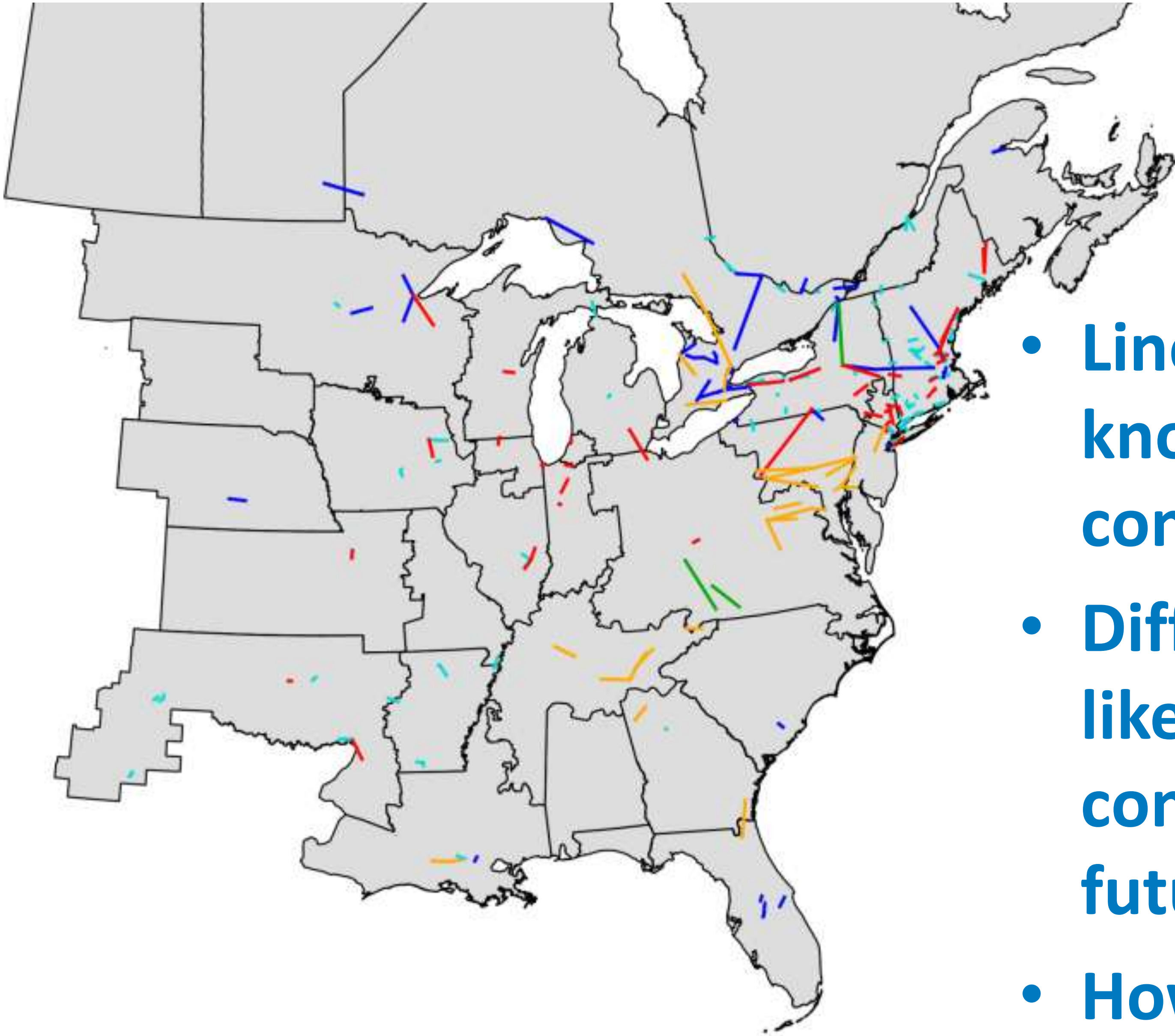
- **Currently possible***
  - But extremely slow runtimes
- **Some inter-regional transfer unconstrained**

Network Simplification: Inter-Zonal Lines



- **Currently possible ***
  - Extremely slow runtimes
- **All intra-regional transfer unconstrained**

Network Simplification: Flowgate Lines



- Lines currently known to be constrained
- Different lines likely to be constrained in future scenarios
- How to choose?

Network Simplification: Proposal

- **Use an equivalencing method to develop a feasible transmission network**
- **Possible improvement[1]:**
  - Node and line count reduced by about 90%
  - DC OPF solution times reduced by about 95%

[1]based on the paper by Shi et al., "Optimal generation investment planning: Pt. 1: network equivalents," *North American Power Symposium (NAPS), 2012*

Runtime Reduction Efforts

Runtime Reductions

- **Exploring runtime reductions possible:**
  - Generator aggregation
    - Native PLEXOS functionality
    - Manual
  - Generator commitment
  - Simplified generator heat rate curves
  - Neglect minimum up/down times
  - Transport model versus DC OPF transmission
  - Time resolution (2-hour vs. 1-hour in DA)
  - Look-ahead (none vs. 1 day at 4-hour resolution)
  - Time-domain parallelization

Generator Aggregation

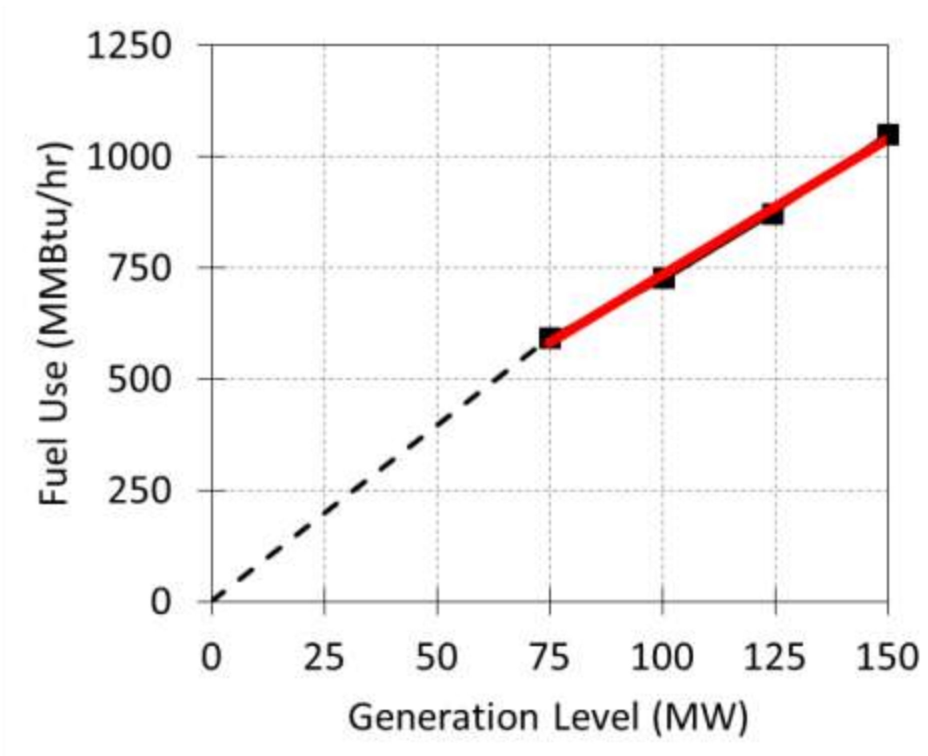
- **Aggregated generators using native Plexos functions**
  - Retains more unit-commitment information
  - Increases compilation time
  - Little net improvement in runtime
- **Aggregated generators outside of Plexos**
  - Little improvement in runtime

Generator Commitment

- **Committed IC, CT, PS units**
  - With no minimum generation level
  - Use constant average heat rate
  - Neglects startup costs and minimum up/down times
  - Up to 25% reduction in runtime

Simplify Generator Heat Rate Curves

- **Constant marginal heat rate**
  - Up to 40% reduction in runtime

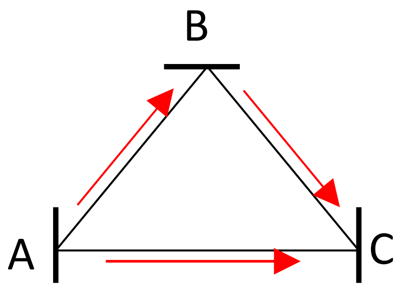


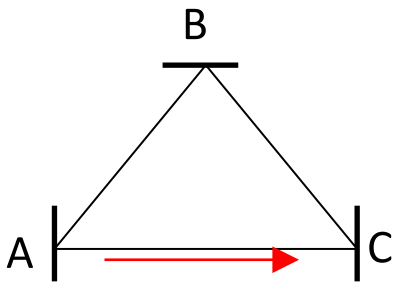
Neglect Minimum Up/Down Times

- **Eliminate minimum uptime and downtime constraints**
- **Reallocate startup costs:**
  - 50% startup
  - 50% shutdown
- **Increased runtimes up to 2x**

Transportation Model vs. DC Power Flow

- **Neglects physics of DC power flow**
- **Up to 75% reduction in runtime**





Decreased Time Resolution

- **Day-ahead operates on 1-hour resolution**
- **Switch to 2-hour resolution**
  - Looses fidelity of actual operational practices
- **Up to 75% reduction in runtime**

Eliminate Look-Ahead

- **Day-ahead has additional look-ahead**
  - One day at 4-hour resolution
  - Prevents unrealistic shut-downs
  - Values energy held in storage
- **Eliminated look-ahead**
- **Did not substantially impact runtime**

Time-Domain Parallelization

- Break down year into months for optimization
- 3 days of overlap for spin-up
- Discard overlap/spin-up periods when aggregating results
- Runtime improvement approximately linear in number of parallel runs
- Improvement limited by longest parallel runtime
- Approximately 90% reduction in runtime

3-Month Plan

3-Month Plan

- **Working Group Meetings?**
  - Transmission
  - Mitigation Options
- **Analysis**
  - 5-minute load paper
  - Net load analysis paper
  - Transmission equivalencing

3-Month Plan

- **Critical steps**
  - Solar DA forecasts
  - Parallelization
  - Transmission equivalencing
  - Import data into PLEXOS
- **Model runs**
  - 2025 No New Renewables Scenario
  - 2025 State RPS Scenario
  - 2025 National Scenario
  - 2025 Regional Scenario

3-Month Plan

- **February TRC Meeting**
  - Denver?
  - Washington, DC?

Contact Us

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